Highway-Railway

Transport Canada
Transports Canada

Canada

103-04773/

TP 13938E

A HUMAN FACTORS ANALYSIS OF HIGHWAY-RAILWAY GRADE CROSSING ACCIDENTS IN CANADA

Prepared for
Transportation Development Centre
Transport Canada

by
Cognitive Ergonomics Research Laboratory
Department of Psychology, University of Calgary

September 2002

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by

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The sponsoring organizations do not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

Because some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

FUNDING PARTNERS
Direction 2006 Highway-Railway Grade Crossing Research Program

Transport Canada
Railway Association of Canada
Canadian National Railway
Canadian Pacific Railway
VIA Rail Canada Inc.
Alberta Transportation
Ministère des Transports du Québec

Ce document est également disponible en français : *‹‹Une analyse des facteurs humains dans les accidents aux passages* à *niveau au Canada››*, TP 13938F.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 13938E

2. Project No.
5027

3. Recipient's Catalogue No.

4. Title and Subtitle
A Human Factors Analysis of Highway-Railway Grade Crossing Accidents in Canada

5. Publication Date
September 2002

6. Performing Organization Document No.

7. Author(s)
J.K. Caird, J.I. Creaser, C.J. Edwards, and R.E. Dewar

8. Transport Canada File No.
ZCD2450-D-718-13-2

9. Performing Organization Name and Address

Cognitive Ergonomics Research Laboratory
Department of Psychology
University of Calgary
Calgary, Alberta
Canada T2N 1N4

10. PWGSC File No.
MTB-0-02198

11. PWGSC or Transport Canada Contract No.
T8200-000552/001/MTB

12. Sponsoring Agency Name and Address

Transportation Development Centre (TDC)
800 René Lévesque Blvd. West
Suite 600
Montreal, Quebec
H3B 1X9

13. Type of Publication and Period Covered
Final

14. Project Officer
S. Vespa and P. Lemay

15. Supplementary Notes (Funding programs, titles of related publications, etc.)

Co-sponsored by the funding partners of the Direction 2006 Highway-Railway Grade Crossing Research program: Railway Association of Canada, Canadian National Railway, Canadian Pacific Railway, VIA Rail Canada Inc., Alberta Transportation, and the ministère des Transports du Québec

16. Abstract

Over the past 10 years, an average of 316 highway-railway grade crossing accidents (not including pedestrian accidents) and 38 fatalities (i.e., vehicle occupants) have occurred each year in Canada. The purpose of this project was to identify human factors contributors to highway-railway grade crossing accidents and to recommend countermeasures based on common patterns of probable cause.

Current signs and signal systems and future technologies were reviewed in terms of effectiveness (i.e., reduction in violations, accidents, injuries and fatalities) and cost. Based on an extensive literature review of human factors crash contributors, a taxonomy of highway-railway grade crossing accident contributors was developed with the primary categories of unsafe actions, individual differences, train visibility, problematic signs and markings, active warning systems, and physical constraints. The taxonomy was used to guide queries of the Transportation Safety Board of Canada's Rail Occurrence Database System.

Quantitative analyses confirmed that overall, accidents, injuries and fatalities are declining. Several demographic (e.g., age, gender), vehicle type, crossing type (i.e., passive, active) and time (day, month) variables revealed a number of expected accident patterns. Qualitative analyses of accident narratives indicated that varieties of intentional acts (e.g., drove around gates) and distraction (e.g., talking on cell phone) were accident contributors. A series of conclusions and recommendations highlight project contributions and knowledge gaps.

17. Key Words

Highway-railway grade crossing accidents, human factors, human error, driver behaviour, countermeasures

18. Distribution Statement
Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)	20. Security Classification (of this page)	21. Declassification (date)	22. No. of Pages	23. Price
Unclassified	Unclassified	—	xxiv, 112, app	Shipping/ Handling

Canada

Transports Canada   Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada TP 13938E	2. N° de l'étude 5027	3. N° de catalogue du destinataire

4. Titre et sous-titre

A Human Factors Analysis of Highway-Railway
Grade Crossing Accidents in Canada

5. Date de la publication

Septembre 2002

6. N° de document de l'organisme exécutant

7. Auteur(s)

J.K. Caird, J.I. Creaser, C.J. Edwards et R.E. Dewar

8. N° de dossier - Transports Canada

ZCD2450-D-718-13-2

9. Nom et adresse de l'organisme exécutant

Laboratoire de recherche en ergonomie cognitive
Département de spychologie
Université de Calgary
Calgary, Alberta
Canada T2N 1N4

10. N° de dossier - TPSGC

MTB-0-02198

11. N° de contrat - TPSGC ou Transports Canada

T8200-000552/001/MTB

12. Nom et adresse de l'organisme parrain

Centre de développement des transports (CDT)
800, boul. René-Lévesque Ouest
Bureau 600
Montréal (Québec)
H3B 1X9

13. Genre de publication et période visée

Final

14. Agent de projet

S. Vespa et P. Lemay

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Coparrainé par les partenaires financiers du Programme de recherche sur les passages à niveau de Direction 2006 : Association des chemins de fer du Canada, Canadien National, Canadien Pacifique, Via Rail Canada Inc., Alberta Transportation et le ministère des Transports du Québec

16. Résumé

Au cours des dix dernières années, on a dénombré, au Canada, une moyenne de 316 accidents aux passages à niveau (sans compter les accidents mettant en cause des piétons) et 38 décès (chez les occupants des véhicules automobiles) par année. L'objectif de ce projet était de cerner les facteurs humains qui entrent en jeu dans les accidents survenant aux passages à niveau et de recommander des contre-mesures qui tiennent compte des tendances observées.

Les panneaux et systèmes de signalisation existants ainsi que les technologies d'avant-garde ont été examinés sous l'angle de leur efficacité (c.-à-d., diminution des infractions, des accidents et du nombre de décès et de blessures) et de leur coût. Après une recherche documentaire exhaustive sur les facteurs humains en cause dans les accidents, les chercheurs ont développé une taxinomie des facteurs humains qui contribuent aux accidents aux passages à niveau, avec, comme grandes catégories : les agissements dangereux, les différences individuelles, la visibilité des trains, les signaux et marquages ambigus et les contraintes physiques. Cette taxinomie a été utilisée pour interroger la base de données sur les événements ferroviaires du Bureau de la sécurité des transports du Canada.

Les analyses quantitatives ont confirmé que dans l'ensemble, les accidents, ainsi que le nombre de décès et de blessures, sont en baisse. L'étude de plusieurs variables, dont des variables démographiques (âge, sexe), le type de véhicule, le type de passage à niveau (automatisé, non automatisé) et le moment (jour, mois) a mis en lumière un certain nombre de tendances que l'on pressentait. Les analyses qualitatives de rapports d'accident ont fait ressortir le rôle de certains actes intentionnels (p. ex., contourner les barrières) et de la distraction (p. ex., utiliser un téléphone cellulaire) dans les accidents. Le rapport se termine sur une série de conclusions et de recommandations qui soulignent l'apport du projet et rappellent les questions qui restent à approfondir.

17. Mots clés Accidents aux passages à niveau, facteurs humains, erreur humaine, comportement des conducteurs, contre-mesures	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication) Non classifiée	20. Classification de sécurité (de cette page) Non classifiée	21. Déclassification (date) —	22. Nombre de pages xxiv, 112, ann.	23. Prix Port et manutention

CDT/TDC 79-005
Rev. 96

Canada

ACKNOWLEDGEMENTS

Portions of the taxonomy (Section 4) and quantitative analyses (Section 6) were presented at the Third Annual Workshop on Highway-Railway Grade Crossing Research in Montreal on November 26th, 2001. The authors would like to thank Nathalie Lewis for her generous assistance accessing and using RODS, Maury Hill and Beth McCullough for the support from the Transportation Safety Board of Canada, and Ling Suen and Sesto Vespa for their project monitoring and guidance. Members of the Steering Committee provided critical feedback at a number of crucial junctures of the contract. In addition to those already mentioned, committee members were Doug Bowron, Marc Fortin, Danielle Gaudreau, Daniel Lafontaine, Ghislain LaFontaine, and Frank Saccamano.

This study is a part of the Highway-Railway Grade Crossing Research Program, an undertaking sponsored by Transport Canada, major Canadian railways, and several provincial authorities. The program is a component of Direction 2006, a cooperative initiative with the goal of halving grade crossing accidents by 2006.

EXECUTIVE SUMMARY

The purpose of this project was to identify human factors contributors to highway-railway grade crossing accidents and to recommend countermeasures based on common patterns of probable cause. The analysis of human factors contributors is expected to make a significant advancement to the knowledge of highway-railway grade crossing accidents in Canada. The project is part of *Direction 2006*, whose purpose is to reduce highway-railway grade crossing collisions by half by the year 2006. Identification and elimination of these accident contributors is essential to the prevention of similar accidents. Ultimately, fewer driver and passenger fatalities and injuries are sought. The project involved three primary research activities:

1) Develop a taxonomy of human factors accident contributors to highway-railway grade crossing incidents based on an extensive review of the research literature.
2) Use the taxonomy to generate quantitative and qualitative queries to the Transportation Safety Board of Canada's (TSB's) Rail Occurrence Database System (RODS).
3) Analyze and interpret the pattern of human factors contributors as it relates to contemporary and intelligent transportation system (ITS) countermeasures.

Literature Review and Taxonomy

One purpose of this project was to extend what is known about highway-railway grade crossing accidents to Canadian data. Based on an extensive literature review, a taxonomy of highway-railway intersection accident contributors was created to generate hypotheses and deductions about specific cases and common patterns of accident contributors (see Figure 1). Unsafe acts, individual differences, train visibility, passive signs and markings, active warning systems, and physical constraints form the primary categories of accident contributors. Unlike other taxonomies, emphasis is placed on multiple contributors to accidents.

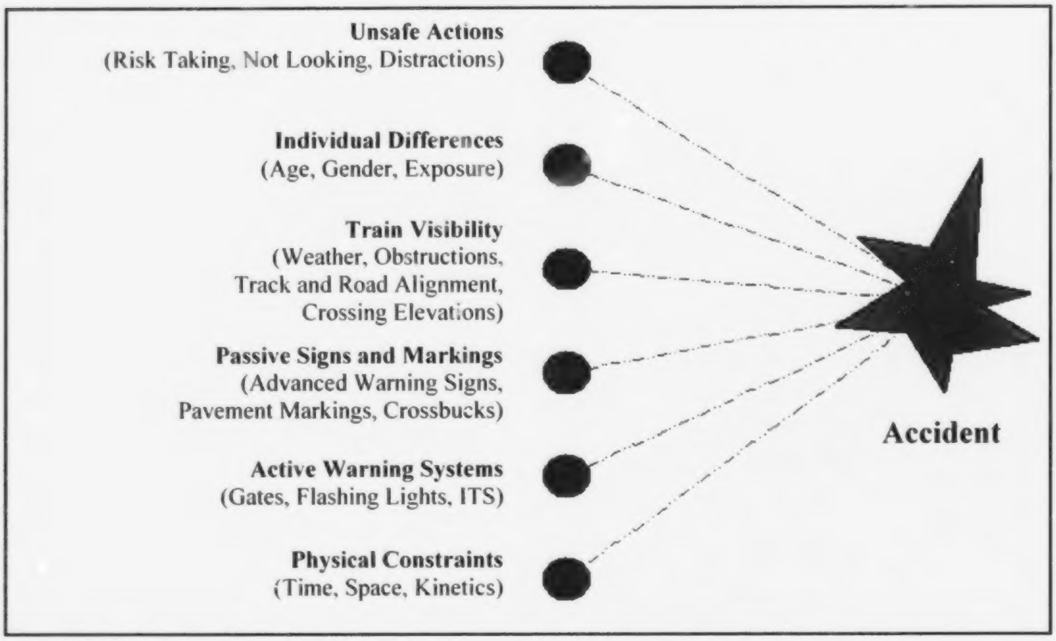
Unsafe Actions
(Risk Taking, Not Looking, Distractions)
Individual Differences
(Age, Gender, Exposure)
Train Visibility
(Weather, Obstructions, Track and Road Alignment, Crossing Elevations)
Passive Signs and Markings
(Advanced Warning Signs, Pavement Markings, Crossbucks)
Active Warning Systems
(Gates, Flashing Lights, ITS)
Physical Constraints
(Time, Space, Kinetics)
Accident

Figure 1 Highway-railway grade crossing accident contributors.

Countermeasure Literature Review

The capacity for current and future grade crossing technologies to reduce the frequency and severity of accidents at highway-railway crossings was reviewed. A number of countermeasure devices have been assessed to determine the reduction of driver accidents with trains. Passive crossings are problematic because of the use of only signage to inform drivers of highway-railway grade crossings. The use of stop signs at passive crossings to increase safety has advantages and disadvantages. Street lights at crossings have been shown to reduce nighttime vehicle-train collisions. The conversion of passive crossings to active crossings, by using flashing lights and bells and gates, has been shown to substantially reduce accidents. Upgrading flashing lights and gates to other countermeasures such as photo-enforcement, median barriers, and four quadrant gates have been shown to reduce the frequency and severity of violation behaviours. ITS offers an alternative to conventional warning systems (both active and passive) currently used at grade crossings. Economic feasibility, however, precludes the installation of active devices at every crossing location. Table 1 shows the effectiveness and cost of a range of countermeasures. The progression of technology is listed by approximate date of introduction.

Means to identify problem highway-railway intersections and install the most appropriate countermeasures are needed. Ultimately, how much safety can be afforded by Transport Canada, the rail companies, and provincial and local governments is likely to determine the scale of possible interventions.

Table 1. Countermeasure Type, Effectiveness, Cost and References.

Countermeasure	**Effectiveness**	**Cost**	**Reference(s)**
Stop Signs at Passive Crossings	Unknown	$1.2 to $2 K (U.S.)	NTSB (1998a)
Intersection Lighting	52% Reduction in Nighttime Accidents over No Lighting	Unknown	Walker & Roberts (1975)
Flashing Lights	64% Reduction in Accidents over Crossbucks Alone; 84% Reduction in Injuries over Crossbucks; 83% Reduction in Deaths over Crossbucks	$20 to $30 K (U.S.) in 1988	Schulte (1975) Morrissey (1980)
Lights & Gates (2) + Flashing Lights	88% Reduction in Accidents over Crossbucks Alone; 93% Reduction in Injuries over Crossbucks; 100% Reduction in Deaths over Crossbucks 44% Reduction in Accidents over Flashing Lights Alone	$150 K (U.S.)	NTSB (1998a) Schulte (1975) Morrissey (1980) Hauer & Persaud (1986)
Median Barriers	80% Reduction in Violations over 2-Gate System	$10 K (U.S.)	Carroll & Haines (2002a)
Long Arm Gates (3/4 of roadway covered)	67 to 84% Reduction in Violations over 2-Gate System	Unknown	Carroll & Haines (2002a)
4-Quadrant Gate Systems	82% Reduction in Violations over 2-Gate System	$125 K (U.S.) from Standard Gates $250 K (U.S.) from Passive Crossing	Carroll & Haines (2002a), Hellman & Carroll (2002)
4-Quadrant Gate System + Median Barriers	92% Reduction in Violations over 2-Gate System	$135 K (U.S.)	Carroll & Haines (2002a)
Crossing Closure	100% Reduction in Violations, Accidents, Injuries and Deaths	$15 K (U.S.)	Carroll & Haines (2002a) NTSB (1998a)
Photo/Video Enforcement	34 to 94% Reduction in Violations	$40 to $70 K per Install (U.S.)	Carroll & Haines (2002b)
In-Vehicle Crossing Safety Advisory Warning Systems (ICSAWS)	Unknown	$5 to $10 K (U.S.) per Crossing + $50 to $250 (U.S.) for a Receiver	NTSB (1998a)

Notes: Countermeasures are listed by approximate date of introduction. The effectiveness of a countermeasure is expressed as a function of the percentage reduction in accidents and other violations over some previous treatment. Cost is expressed in U.S. dollars for the most recent reference.

Quantitative Analysis

The quantitative analysis characterized Canadian highway-railway grade crossing accidents over the past 19 years. To achieve this objective, RODS was queried with a range of quantitative and qualitative research questions based on the taxonomy of accident contributors. The quantitative results of the RODS queries indicate that the frequency of highway-railway grade crossing accidents, injuries, and fatalities per million train miles has declined (see Figure 2). Vehicle occupant fatalities are quite variable from year to year. Prior to 1993, data were not broken into passenger/driver categories. Injury classification changed in 1993 from reportable injuries to serious injuries only. The reclassification resulted in a notable drop in injuries. Dangerous goods accidents are relatively constant.

Accidents at both public automated and public passive crossings have declined since 1983, and public automated crossings experienced more accidents overall than any other type of crossing. After 1993, all private and farm crossing accidents were required to be reported, and show an increase in accidents that is reflective of the reporting change.

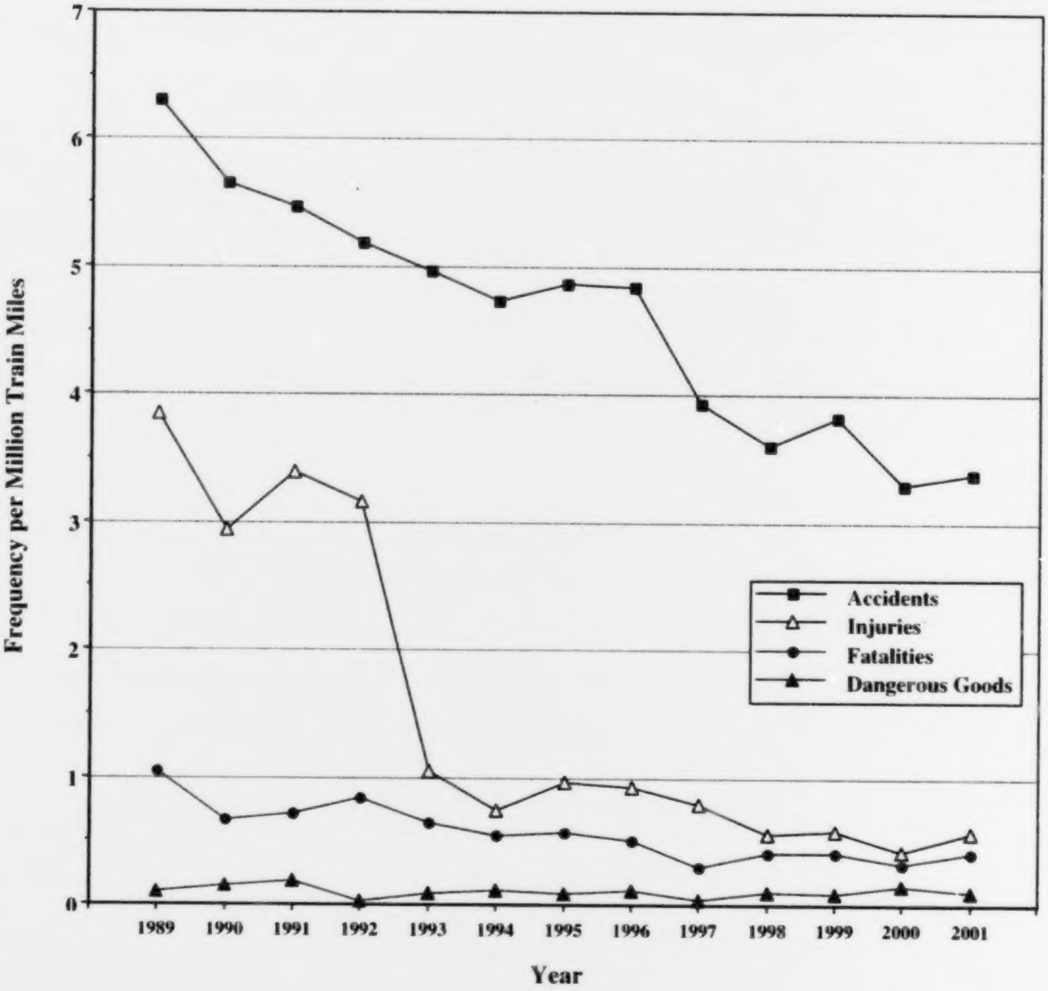

Figure 2 Frequency of accidents, injuries, fatalities, and dangerous goods per million train miles from 1989-2001.

A number of the results are summarized:

- For all RODS crossing accidents (N = 7,819), the majority (50%) occurred at crossings with an angle of less than 80° (or more than 100°).

- Automobiles were involved in the majority of fatal accidents since 1983 (53%), followed by light trucks (27.1%), vans (5.3%), heavy trucks (4.6%), and tractor trailers (3.6%). Dangerous goods trucks were only involved in 0.23% of all fatal vehicle accidents.

- Only a small number of fatal accidents after 1993 (N = 155) had both gender and age information. In this small sample, male drivers aged 26 to 64 had the highest fatal accident frequency (49%) and female drivers aged 26 to 64 had the next highest frequency (17.4%).

- Data averaged from 1983-2000 indicate that January and December have the highest percent of accidents per year and April has the lowest.

- The majority of accidents (approx. 40%) occurred during daylight hours (9:30 a.m. to 3:30 p.m.), and 29% occurred during the morning (6:30 a.m. to 9:30 a.m.) and evening (3:30 p.m. to 6:30 p.m.) rush hours.

- Based on vehicle and train flows at crossings, the majority of accidents happen at crossings with fewer than 500 vehicles crossing per day.

- With some expected variance (e.g., weather, traffic flow), Canadian highway-railway grade crossing accident patterns are somewhat similar to those in the U.S.

- Finally, where driver behaviour was categorized as an intentional unsafe act, the actions "failed to stop" and "drove around gates" were ranked first and second.

Qualitative Analysis

The qualitative analysis provided additional descriptions of patterns of accidents associated with intentional acts and distraction-related accidents. The importance of providing elaboration of accidents is to provide convergent evidence to support the quantitative analyses and to provide in-depth descriptions. To our knowledge, the application of this method to highway-railway crossing accidents has not been done previously. Keyword search was used to query 3,990 narratives logged between January 1, 1990, and November 7, 2001. As well as providing rich accident descriptions, the narratives revealed expected contributors:

- A number of narratives revealed multiple accident contributors, providing a more detailed look at how driver behaviour interacts with various conditions to cause an accident.

- Eighty-six narratives indicated an intentional action as a contributing factor to an accident. For behaviours classified as intentional, 35 drivers drove around the gates, 16 drivers attempted to beat the train, 10 stopped or slowed, then proceeded, 4 drove around vehicles stopped or slowing at a crossing (without gates), and 4 drove around stopped vehicles and gates. An additional 5 accidents were related to alcohol impairment and 3 were related to fatigue.

- Thirty-nine narratives revealed the possibility of driver distraction as a contributing factor. In 12 the driver completely failed to see the train/signals and in 10 the driver failed to see the train in time to stop. Seven narratives noted cellular phone use, 4 involved internal distraction (e.g., cognitive processes), 3 indicated the presence of passengers in the vehicle, 3 involved external distraction (events/objects outside the vehicle), and 1 involved the driver adjusting the radio/tape player in the vehicle.

- Sixty-four narratives indicated visibility problems. In particular, fog (25), sun glare (21), snow (8), and poor sight-line conditions (10) were identified as contributors to accidents.

- Crossings adjacent to a road-road intersection were identified in 31 narratives and in 10 second-train accidents.

Conclusions and Recommendations

1) The significance of this project was the characterization of Canadian highway-railway grade crossing accidents over time and in depth from a human factors perspective. The quantitative and qualitative analyses supplemented by the TSB unsafe acts and conditions categorizations provide a thorough and unique description of Canadian highway-railway accidents. Statistical comparisons can be made based on replications and extensions to the present research.

2) Comparisons between TSB highway-rail grade crossing accidents and Federal Railroad Administration (FRA) incidents for 2000 indicate similar patterns for gender, time of day and month, vehicle type, and warning type. Weather involvements were different, as expected. Unsafe acts and conditions, crossing angle, driver age, and long-term trends could not be compared.

3) Observations of driver behaviour at highway-railway intersections provide insight into the effectiveness of a variety of countermeasures. Crossing familiarity and an expectation that a train will not be present have the potential to lull drivers into complacency or poor looking habits. Automatic warnings that prevent train-vehicle interactions altogether have the greatest potential to reduce accidents, injuries and fatalities. Complete closure and median barriers at already gated crossings are attractive for cost and effectiveness reasons.

4) Although stop signs provide consistent information to drivers, FRA statistics of their involvement in accidents and fatalities are cause for concern. Stop signs at highway-railway grade crossings are frequently disregarded by drivers. The effectiveness of stop signs in reducing accidents over existing accident rates has not been established. If Canada were to consider the National Transportation Safety Board's recommendation for stop sign use, additional research is needed to establish its effectiveness.

5) Supplementary advance warning signs that indicate what drivers should do as they approach a crossing should be developed and evaluated. In some countries (e.g., Australia, Israel, U.K.), supplementary information may include distance to the crossing and information such as "look for trains" and "do not stop on tracks". Because drivers fail to notice advance warning signs, multiple signs should also be considered.

6) Countermeasure effectiveness can be established using a number of methods (see, e.g., Hauer & Persaud, 1986). However, the net effect of extensive countermeasure deployment on the overall accidents, injuries and fatalities cannot be established conclusively (e.g., see Evans, 1985; 1991). The integration of countermeasures at problem highway-railway grade crossings will contribute to the historical reductions already realized. The reduction of accidents,

injuries and fatalities will occur with uncertain variability that will be difficult to attribute to any specific countermeasure program.

7) At first inspection, highway-railway accidents appear relatively simple with few contributors beyond the accident scene. However, in-depth investigations of highway-railway accidents may yield additional contributors if the question of why is repeatedly asked. Root cause analysis implies a search for the ultimate cause or causes to an accident (e.g., Leveson, 1995; Rasmussen, 1990; Reason, 1990). Root cause analyses are helpful where organizations may contribute to the occurrence of an accident. Organizational contributors may include the lack of coordination between rail companies and road authorities to resolve unsafe conditions at a crossing. A targeted Class IV investigation by the TSB may yield the extent to which these organizational contributors exist. The extent to which they exist is currently unknown.

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GLOSSARY

The precision of language used to describe highway-railway grade crossing accidents is important. The use of terms throughout the report is consistent with the organization that is cited (e.g., FRA, NTSB, TSB). A verbal and visual description of highway-railway grade crossing elements is found in Section 2 of this report. For the qualitative and quantitative analyses, TSB terminology is used unless otherwise noted.

AASHTO—American Association of State Highway and Transportation Officials

ADT—Average Daily Traffic

ATCS—Advanced Train Control System

Accident—seen as unpredictable and random. Thus, *accidents do happen to us*; they are at least part chance. In general, *accidents are not something people do* (Senders & Moray, 1991, pg. 28, italics original). An "accident" implies a lack of intent (Robertson, 1998).

Accident Risk—the chance or probability of an accident in the future (Davies, 1996).

Active Crossing—a crossing where flashing lights and bells (FLB) and/or gates are not activated unless a train is approaching (Mortimer, 1988). The active elements of the crossing indicate that a train is coming.

Advance Warning Sign (AWS)—a sign used to indicate the presence of an upcoming passive or active highway-railway grade crossing.

Automated Crossing—synonymous with active crossing above.

Error—human action that fails to meet an implicit or explicit standard (Senders & Moray, 1991, pg. 20).

FLB—Flashing Lights and Bells

FRA—Federal Railroad Administration (U.S.)

Grade-Crossing Collision—a collision that occurs at any railway crossing between rolling stock and any other crossing user (TSB, 1992, August, pg. 2).

Highway-Railway Grade Crossing Incident—any impact between highway users (both motor vehicle operators and other users of the crossing) and a train at a designated crossing site (FRA, 2001, pg. 1).

HUD—Head-up Display

Incident—reportable event that includes, among other events, impacts between railway, track equipment, and highway users (FRA, 2001, pg. 1).

IRIS—Integrated Rail Information System

ITS—Intelligent Transportation System

ITW—In-vehicle Train Warning

LED—Light Emitting Diode

LRT—Light Rail Transit

MTM—Million Train Miles

MUTCDC—Manual of Uniform Traffic Control Devices for Canada

NTSB—National Transportation Safety Board (U.S.)

Passive Crossing—crossing where no warning is given from train-activated devices.

PRT—Perception Response Time

Railway Incident—incident resulting directly from the operation of rolling stock, where: a) a risk of collision occurs; etc.
(TSB, www.tsb.gc.ca/ENG/stats/Rail/Year00/rail-eng.hrm#APPENDIX 1)

Railway Occurrence—a) any accident or incident associated with the operation of rolling stock on a railroad, and b) any situation or condition that the Board has reasonable grounds to believe could, if left unattended, induce an accident or incident described in paragraph (a) above (TSB, www.tsb.gc.ca/ENG/stats/Rail/Year00/rail-eng.hrm#APPENDIX 1)

RCMP—Royal Canadian Mounted Police

RODS—TSB Rail Occurrence Database System

Serious Injury—any injury that is likely to require admission to a hospital (TSB, 1992, August, pg. 6).

TAC—Transportation Association of Canada

TDC—Transportion Development Centre

TSB—Transportation Safety Board of Canada

Unsafe Act—more than just an error or a violation; it is an error or violation committed in the presence of a potential hazard: some mass, energy, or toxicity that, if not properly controlled, could cause injury or damage (Reason, 1990, pg. 206).

Violation—deviations from those practices deemed necessary (by designers, managers, or regulatory agencies) to maintain the safe operation of a potentially dangerous system (Reason, 1990, pg. 195).

1. INTRODUCTION

The purpose of this project was to identify human factors contributors to highway-railway grade crossing accidents and to recommend countermeasures based on common patterns of probable cause. The project was sponsored by the Transportation Development Centre (TDC) with the support of the Transportation Safety Board of Canada (TSB).

The analysis of human factors contributors is expected to make a significant contribution to the knowledge about highway-railway grade crossing accidents in Canada. Ultimately, reductions in driver and passenger fatalities and injuries are sought.

1.1 Project Objectives

The project involved three primary research activities:

1) Develop a taxonomy of human factors accident contributors to highway-railway grade crossing accidents based on an extensive review of the research literature.

2) Use the taxonomy to query the TSB's Rail Occurance Database System (RODS) both quantitatively and qualitatively.

3) Analyze and interpret the pattern of human factors contributors as it relates to contemporary and intelligent transportation system (ITS) countermeasures.

1.2 Project Scope

Analysis of literature and data was limited to vehicle accidents where the driver, passenger or vehicle was involved. Pedestrian and trespasser accidents were explicitly excluded from analyses and were considered under a separate TDC contract.

The sections of this report that follow address facets of each of the project objectives. Canadian highway-railway crossing elements as specified in the *Manual of Uniform Traffic Control Devices for Canada* (MUTCDC) and other references are briefly introduced. From a driver's point of view, the information available that indicates a crossing is approaching is important to understand where, when, why and how trains may or may not be seen. For example, crossbuck signs, bells and lights, and pavement markings are frequently present. The literature on accident epidemiology, driver behaviour, observational studies and others are dealt with in Section 3. Based on the literature, a taxonomy of human factors contributors is described in Section 4, as are potential applications for the taxonomy. A review of contemporary and future countermeasures to prevent railway crossing accidents follows the taxonomy. Quantitative analyses of the RODS are described in Section 6. These analyses involve the frequency of certain accidents as classified by using a number of descriptors such as age, location and so forth. New to all highway-railway crossing analysis is a section of qualitative analyses of accident narratives. Qualitative analyses involve searching narratives for keywords such as "willful violation" or "distracted" to determine whether these factors were involved in any accident. The last section synthesizes important information from reviews and analysis; future research is also considered.

1.3 Mandate of the Transportation Safety Board

The TSB's mandate is to advance transportation safety by investigating transportation accidents within the domains of rail, pipelines, marine and aviation by:

- conducting independent investigations, including, when necessary, public inquiries into selected transportation occurrences in order to make findings as to their causes and contributing factors;
- identifying safety deficiencies as evidenced by transportation occurrences;
- making recommendations designed to eliminate or reduce any such safety deficiencies; and
- reporting publicly on its investigations on the findings in relation thereto.

In terms of the TSB's RODS that was analyzed for this study, as of 1993 it was used to document all rail occurrences on federally regulated track. Before 1993, all public crossing accidents on federally regulated track were reported, but accidents at farm/private crossings were reported only if they involved casualties (minor/serious injuries or fatalities), dangerous goods, or a derailment resulting in property damage in excess of $7,350 for main-track operations. Neither provincially regulated lines nor highways are included in the TSB's database or covered by the mandate. Ultimately, the data collected are used to identify safety deficiencies and, possibly, issuance of safety communications to address these and, thus, advance transportation safety. Therefore, the focus of RODS is on rail information, and the inclusion of information related to highways and driver behaviour at crossings is secondary, depending on the nature of a grade crossing occurrence. Although the TSB's mandate does not focus on highway safety, railway grade crossings are an unavoidable part of the railway system within Canada. Therefore, understanding the interaction between drivers and crossings is essential to improve the safety of the rail system in Canada. Over the years, the TSB has increasingly included information related to driver behaviour, such as in the unsafe conditions and acts section of RODS.

Ultimately, the TSB does not rank types of accidents in terms of importance. It reviews developments in transportation safety and highlights recurring and serious issues by maintaining a list of significant safety concerns. This list is reviewed annually to determine whether there are issues that should be added because of risk potential or issues that should be removed because the associated risks have been mitigated. Collisions at railway crossings were on the 2001 Key Safety Issues List, but only in the context of managing construction safety at grade crossings in terms of the safe passage of vehicles at locations experiencing construction.

1.4 Levels of Classification and Mandatory Reporting Requirements

There are five levels of investigation categorization within the TSB that apply to occurrences within RODS.

- A Class 1 occurrence involves a public inquiry into an occurrence the TSB is investigating.
- An occurrence is classified as 2 or 3 and investigated when it is expected, inter alia, that there may be a high probability for advancing safety or understanding latent conditions contributing to a significant safety issue.

- A Class 4 occurrence involves the analysis of multiple occurrences to investigate a significant safety issue.
- A Class 5 occurrence does not meet the criteria for Classes 1 through 4; data pertaining to a Class 5 are collected for the purposes of statistical reporting and possible future safety analysis.

The bulk of grade crossing occurrences within RODS are designated Class 5 occurrences.

The following are the mandatory reporting requirements for reportable railway accidents and incidents as outlined in the TSB regulations: "Subject to subsection (5), where a reportable railway accident or incident takes place, the railway company, the track operator and any crew member aboard the rolling stock involved in the accident or incident shall report to the Board as much of the information listed in subsection (2) as is available, as soon as possible and by the quickest means available.

> (2) The report referred to in subsection (1) shall contain the following information:
>
> a) the train number and direction;
> b) the names of the railway company and of the track operator;
> c) the names of the crew members;
> d) the date and time of the accident or incident;
> e) the location of the accident or incident by reference to a mileage and subdivision location and, where applicable, the track designation in a yard;
> f) the number of crew members, passengers and other persons that were killed or sustained a serious injury;
> g) a description of the accident or incident and the extent of any resulting damage to the rolling stock, the railway, a commodity pipeline, the environment and other property;
> h) a summary description of any dangerous goods contained in or released from the rolling stock;
> i) in the case of a reportable accident, the anticipated time of arrival of wreck-clearing equipment; and

j) the name, location and title of the person making the report."

In addition to the mandatory information outlined above, RODS may also contain additional information on the train, track, rolling stock, environmental conditions, unsafe conditions/acts, the crossing, etc., depending on the occurrence class and specifics of the occurrence. Despite the somewhat limited nature of RODS data in terms of highway safety, there are several valuable observations that can be drawn from the data within RODS because of the large number of incidents archived since 1983. In particular, the qualitative narrative search revealed several aspects of driver behaviour at railway grade crossings despite not having a mandated focus on highway safety. Furthermore, the addition of the unsafe conditions and acts section changed the way driver behaviour was logged for an occurrence.

2. CANADIAN CROSSING STANDARDS

A succinct overview of the tasks that drivers perform as they encounter various kinds of signs and controls is important for understanding different crossing types and the human factors considerations of highway-railway crossings. An elegant task analysis of highway-railway crossing is given in Lerner et al. (1990). However, a number of sign and signal differences exist between the U.S. and Canada, and these are introduced.

Highway engineering guidelines for advance warning signs (AWS) and signals at highway-railway grade crossings are frequently more than 50 years old (NTSB, 1998a). Compliance with guidelines such as those in the MUTCDC, *A Policy Geometric Design of Highways and Streets* (often called the AASHTO Greenbook), the Transportation Association of Canada's (TAC) *Geometric Design Guide for Canadian Roads*, the *Highway-Railroad Grade Crossing Handbook* and others is not always uniformly achieved. For example, 55 of 60 passive highway-railway grade crossings investigated by the National Transportation Safety Board (NTSB) (1998a) did not adhere to one or more design guidelines. Existing Canadian highway-railway grade crossing standards for crossing geometry (Transport Canada, 2002a) and active warning devices (Transport Canada, 2002b) can be found at the Transport Canada website (www.tc.gc.ca/acts-regulations/GENERAL/R/rsa/menu.htm). A draft document titled *Road/Railway Grade Crossing Manual* can be found at www.tc.gc.ca/railway/RSCC/RSCC.htm (also see Transport Canada, 2002c). A brief review of what these signs and signals are at passive and active crossings is important for the literature reviews and analyses that follow.

2.1 Passive Crossing Approaches

During an approach to a passive grade crossing, the driver is potentially exposed to different warning devices to draw attention to the upcoming crossing. It is assumed that rational drivers intend to travel over the highway-railway grade crossing safely and successfully. On approach to the crossing, the driver must first be aware the grade crossing exists. The AWS's located before every grade crossing are designed to provide such information. AWS information can be displayed in a variety of ways depending on the angle of the roadway approach and whether there are intersections prior to the crossing. Sight distance, that is the visibility down the tracks in each direction, is critical to the driver about 8 to 12 seconds before reaching the crossing. Drivers must be warned of a crossing so they have time to scan for trains and stop in time if necessary. Sight distances can be obstructed by trees, buildings, and the roadway-crossing geometry. Detection of an approaching train becomes more difficult in these cases. Past the AWS, pavement markings indicate to drivers that they are close to the crossing. Pavement marking locations depend on posted speed, environment, and road type. A crossbuck sign provides the last indication to the driver where the crossing is located. In addition, a multiple track sign under the crossbuck tells the driver the number of tracks to expect when there is more than a single track. Stop lines and stop signs may indicate, in certain circumstances, where the driver should stop.

2.2 Automated Crossings

On approach to a crossing with an automated warning, drivers are notified of a train's presence through the use of flashing lights (visual) and bells (aural). These warnings provide a better assessment of the likelihood of an oncoming train than at passive crossings. The lights and bells are activated through a train sensor for a minimum of 20 seconds before the arrival of the train. AWS's and pavement markings provide redundant passive warning information, indicating the presence of a grade crossing. When the bells and signals are activated, the visual attention of the driver should be directed toward the lights. The correct response at this stage is for the driver to slow down, stop and then enter the crossing once it is safe to do so. At some locations, gates block the travel of the vehicle onto the tracks. A further description of the warning devices used at railway grade crossings is provided throughout this section.

2.3 Advance Warning Signs

A set of passive traffic control systems is located prior to and at railway crossings. In accordance with the MUTCDC, placement of the AWS depends on train velocity, track and roadway usage, and the maximum speed limit on the roadway. The sign is used as a warning measure indicating the presence of the upcoming highway-railway crossing. The sign is a diamond shape 750 mm x 750 mm, incorporating a black depiction of the railway tracks intersecting the roadway on a yellow background (e.g., see W18-20, MUTCDC). Variations of the sign indicate the location of the tracks relative to an intersection (see Figure 2.1). AWS's (WA-18R) depicting the railway track crossing the roadway at an angle are used at skew-angle crossings, since those configurations can present visibility problems. An advisory speed tab sign may also be placed below the AWS to indicate a recommended vehicle velocity when sight distances are limited.

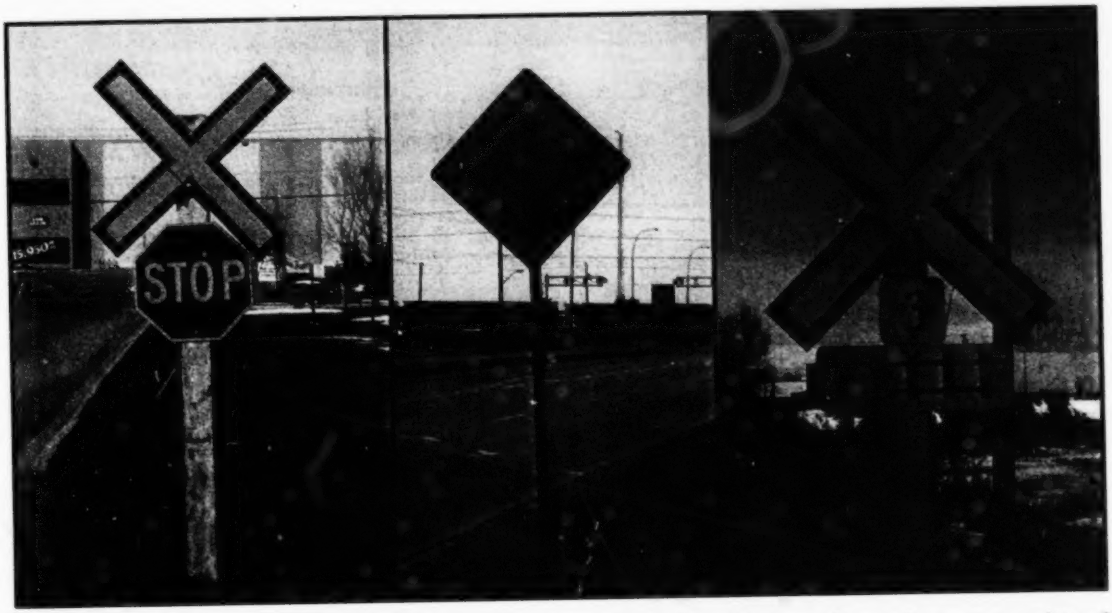

Figure 2.1 Advance Warning Signs: crossbuck (RA-6) with stop sign, advance warning sign, crossbuck with multiple track signage (RA-6s).

2.4 Crossbucks and Multiple Tracks

Crossbucks are located at all grade crossings on both approaches to the crossing. They are intended to indicate that drivers must yield the right of way to trains. The crossbucks form an X via the intersection of two 1200 mm x 200 mm retro-reflective pieces and are attached to a post also marked with retro-reflective material. The post height depends on the environmental conditions associated with each railway grade crossing. Multiple track signage is required when there is more than one track present and is attached below the crossbuck sign.

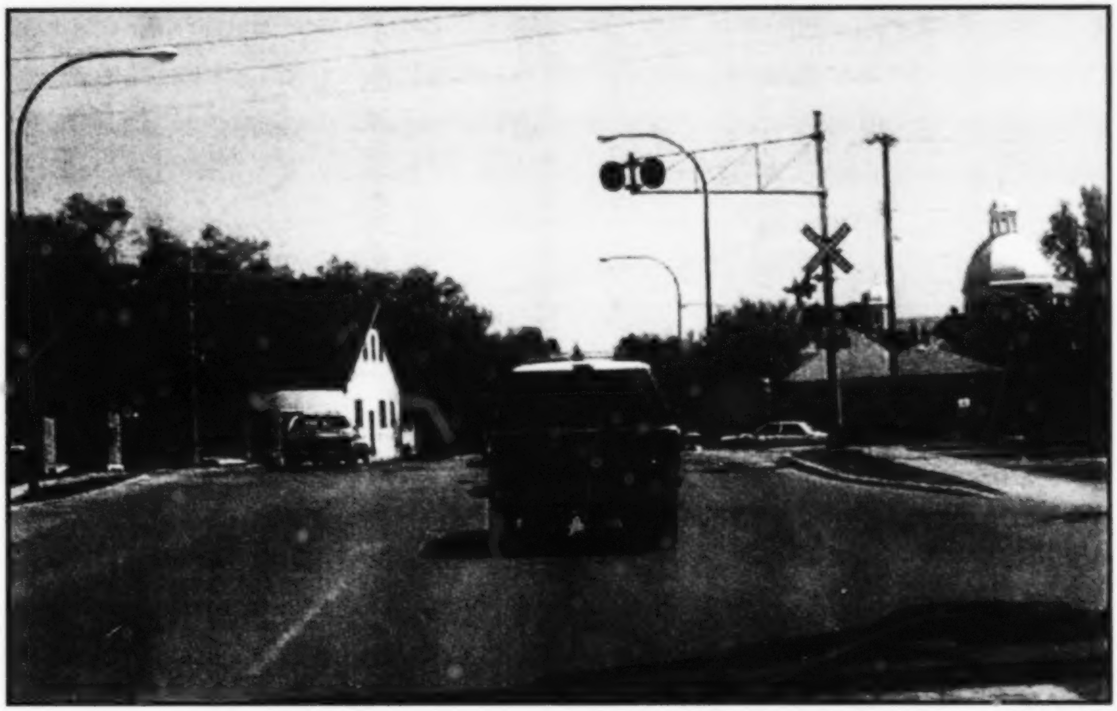

Figure 2.2 Crossbuck, lights on a pole and cantilevered over the roadway, 2-track sign and overhead lights in suburban Winnipeg.

2.5 Stop Signs

Stop sign placement at highway-railway grade crossings can occur in rural settings. Stop signs are used to influence the driver to visually scan for oncoming trains and are usually placed where sight distances are inadequate at a crossing. Placement is further contingent on track and road usage statistics. Drivers must stop their vehicle and visually assess the tracks for the presence of a train before proceeding. Minimum standard stop sign dimensions are 600 mm x 600 mm and sign shape is octagonal. Oversized stop signs may be used when regular stop sign size is insufficient, which may depend on environmental factors.

2.6 Additional Signage

Additional signage can be used depending on the railway grade crossing environment. Warning signs indicating specific criteria can be placed in accordance with established restrictions. For example, when the crossing is near an intersection, a "no stopping on tracks" sign may be used to warn drivers not to stop on the crossing, even when traffic is backed up. There is currently no regulation in place regarding the addition of "no stopping on tracks" signs. However, the "no stopping on tracks" sign is currently under development by TAC.

2.7 Automated Warning Devices

In addition to the crossbucks encountered at the railway grade crossing, those crossings with high levels of train and vehicle activity also employ automated warning devices to supplement detection by drivers. An automated crossing can employ visual warnings, flashing lights, and an auditory warning in the form of a bell. Some crossings employ further safeguards in the form of gates to restrict drivers from proceeding into the crossing. The deployment of signals, bells, and gates depends on the engineering and safety requirements. The signals are located horizontally below the crossbucks and/or above the roadway. Auditory warnings include bells to warn other road users, such as pedestrians and bicyclists.

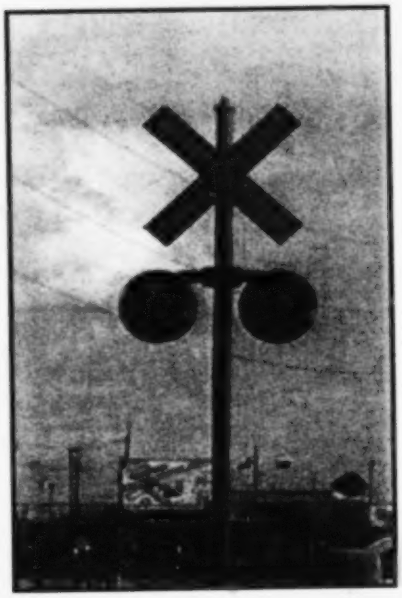

Figure 2.3 Automated warnings: crossbuck sign with flashing lights.

The primary warning devices at active crossings are flashing red lights. These are either 20 or 30 cm (8 or 12 in.) in diameter. The latter are somewhat more effective, as they have an area of more than double the 20 cm (8 in.) lights (Glennon, 1996). A limitation of these lights is that they have a limited viewing cone to concentrate the light toward approaching drivers. Therefore, the lights must be carefully aimed to cover the appropriate length of road, and extra lights may need to be installed if an approaching road is curved or at an angle to the tracks.

2.8 Roadway Pavement Markings

Pavement markings are painted on the roadway just past the AWS and before a highway-railway crossing. The pavement markings consist of a large "X" with a stroke width of 300 to 500 mm. Dimensions of the "X" are 6.0 m long and 2.5 m wide. Retro-reflective paint must be used and the "X" must be incorporated on each side of the road before the railway grade crossing. The centre of the cross marking is located 10 m from the AWS.

Two white stop lines across the width of the driving lanes, 300 mm wide and 300 mm apart, at a distance of 4.5 m from the nearest track indicate where drivers are to stop when a train is approaching.

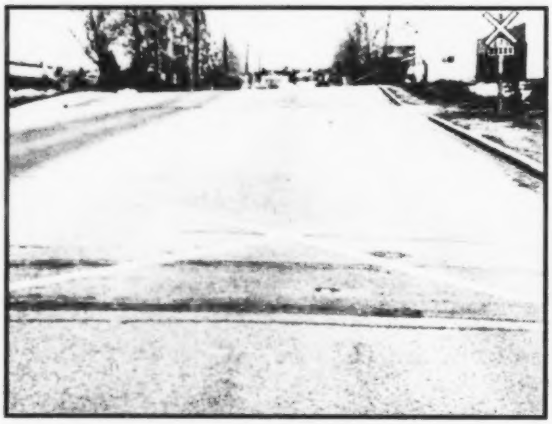

Figure 2.4 Highway pavement markings before crossing.

3. LITERATURE REVIEW

A tragic example of a highway-railway grade crossing accident was the collision of a school bus and a commuter train in Fox River Grove, Illinois, on October 25, 1995. Seven children were killed and 25 were injured. The NTSB conducted an intensive accident investigation and identified numerous driver training, signal integration, crossing design, and emergency communication issues that were likely accident contributors (NTSB, 1996). The accident was tragic but did enhance public awareness and promoted the need to improve highway-railway grade crossings. Although two bus-train accidents have happened in Canada over the past 19 years, a similar catastrophic event has not yet happened here.

Successive generations of researchers have addressed the problems of highway-railway grade crossings. In both the U.S. and Canada, research activity has increased in recent years. Human factors analysis of grade crossing accidents has been the focus of research projects in Australia (e.g., Wigglesworth, 1979), Sweden (Åberg, 1988), Israel (Shinar & Raz, 1982), and the U.S. (e.g., Klein et al., 1994; Lerner et al., 1990). Accident contributors such as train visibility (Abrams, 1995; Wigglesworth, 1979), advance signs (NTSB, 1998a), active warnings (e.g., Mortimer, 1988; Shinar & Raz, 1982), driver behaviour (Abraham et al., 1998; Lerner et al., 1990), driver distraction (Åberg, 1988), and risk taking (Ward & Wilde, 1995a) have been identified as common human factors contributors to vehicle-train grade crossing accidents. Generally, the majority of highway-railway grade crossing accidents occur during daylight hours and in good weather conditions (NTSB, 1986; NTSB, 1998a; Wigglesworth, 1979). It is the interaction of several contributing factors, such as driver behaviour and crossing characteristics, that causes most accidents (Berg et al., 1982; NTSB, 1986). Previous research continues to lend insight into difficulties that drivers experience when encountering a highway-railway crossing.

Research that identifies specific human factors contributors to Canadian grade crossing accidents is lacking. A human factors analysis of highway-railway grade crossing accidents seeks to place human error in the context of perceptual, memory, cognitive, and motor capabilities (e.g., see Caird & Hancock, 2002; Leibowitz, 1985). The purpose of this project is to extend what is known about highway-railway grade crossing accidents to Canadian data. Whether the same safety issues found in other studies are prevalent in Canada is an open question that will be addressed by this project.

3.1 Methods

A number of methods were used to identify important literature sources about human factors and driver behaviour at highway-railway crossings. Searches of specific literature were conducted on known excellent papers, on the web, through manual database searches, and on reviews of major bibliographies compiled by other authors. In addition to human factors and behavioural contributors, human error and grade crossing countermeasure research efforts were added to supplement the error taxonomy (Section 4) and countermeasure (Section 5) sections, respectively.

3.2 Driver Behaviour at Highway-Railway Grade Crossings

Drivers engage in numerous behaviours at crossings that may increase the risk of an accident. A 1986 NTSB safety study that investigated 75 of 161 reported grade crossing accidents involving passenger trains in 1985 attributed driver behaviour as a causal factor in 52 out of the 75 (69%) accidents reviewed (NTSB, 1986). In a more recent study on passive grade crossing accidents, the NTSB attributed driver error as a cause in 49 out of 60 cases investigated (NTSB, 1998a). For example, the driver "disregarded a stop sign" in 13 cases, "failed to look for a train" in 16, was "distracted" in 10, and had a "judgement error" in 5. In the remaining 11 non driver-related accidents, 7 involved roadway conditions that limited the drivers' ability to see the crossing or train. One case involved a vehicle maintenance failure. Although not necessarily a representative sample of accident cases, the 60 passive crossing cases were selected along a number of dimensions, including time of day, injury severity, fatality, public versus private crossing, train speed, train conspicuity, and train horn sounded.

3.2.1 Crossing Familiarity

In case study investigations of highway-railway grade crossing accidents, findings often indicate that many drivers were familiar with the crossing (Wigglesworth, 1979; NTSB, 1986). For example, Wigglesworth (1979) investigated a sample of 85 fatal accidents that occurred at crossings in Victoria, Australia, between 1973 and 1977. Seventy-three of the 85 drivers (86%) were considered to be familiar with the crossings at which their accidents occurred. The classification of whether an individual was familiar or unfamiliar with a crossing was based on whether the crossing was within one mile of the driver's home address. Wigglesworth suggested that some of the drivers deemed "not local" could actually be familiar with the crossing, especially if it was close to their residence or place of employment. It could also be possible that some drivers deemed "local" might rarely drive over a crossing in their area because there was no need to.

Similar to Wigglesworth's (1979) findings, the 1986 NTSB study estimated that approximately 85% of the drivers were familiar with the grade crossing. However, the NTSB study did not mention how familiarity was determined. In an investigation of driver violations at active crossings, Abraham et al. (1998) reported that 68% of 276 drivers who were questioned after committing a violation at a crossing said they used the crossing at least 4 times a week, and 19% said they used the crossing 2 to 4 times a week.

Overall, familiarity with a crossing may influence how individuals approach a crossing. In Wigglesworth's 1979 study, for example, a driver was hit at a crossing that he used at the same time every day by a train that was two hours late. Moreover, the findings of Abraham et al. (1998) revealed that 87% of drivers who committed a violation at an active crossing used the crossing regularly. This result suggests that familiarity may encourage drivers to take greater risks. In the Abraham et al. study, most drivers said they ignored the signals or went around barriers because the "train was not in sight" or the "train was stopped for an unreasonable amount of time." Ultimately, it is extremely difficult to determine or comprehend the full nature of a driver's actions and decisions regarding a crossing. Determination of familiarity is difficult unless drivers are specifically queried about their familiarity with the crossing. An operational definition of familiarity is needed if potential differences in driver behaviour at familiar and unfamiliar crossings are to be investigated in future studies. For example, does a driver need to use a crossing every day, a few times a week, or a few times a month to be considered familiar with it? A comparison of familiar and unfamiliar drivers with the degree that each is involved in accidents would determine whether familiarity is just a reflection of exposure. Finally, investigations of fatal accidents (e.g., Wigglesworth, 1979) are unlikely to yield an accurate picture of familiarity as drivers who are fatally injured cannot testify to their familiarity with a crossing.

3.2.2 Slowing Behaviour During Crossing Approaches

Several observational studies document the slowing behaviour of drivers on the approach to a crossing (Shinar & Raz, 1982; Ward & Wilde, 1995b; Moon & Coleman, 1999). However, whether drivers slow down to scan for trains or for other reasons is difficult to determine. They may be slowing because of traffic congestion ahead or for other reasons (e.g., anticipating a rough crossing). Furthermore, the actual slowing that occurs at crossings may reduce the safety of the driver (Shinar & Raz, 1982; Moon & Coleman, 1999).

Shinar and Raz (1982) investigated driver behaviour at a railway grade crossing in Israel with five different conditions. One crossing was used and modified a number of times to achieve the following conditions:

1) Passive: the flashing lights at the crossing were covered and signs that read "Slow, signal out of order" were placed at 160 m and 30 m before the crossing.
2) Flashing lights not activated: data collected when no train approaching.
3) Flashing lights activated: data collected when a train was less than 40 seconds away.
4) Flashing lights and half gates not activated: data collected when no train coming.
5) Flashing lights and half gates activated: data collected when lights on and gates down.

All of the conditions listed above had the standard Israeli warning signs before the crossing, which include a progression of pairs of 3, 2 and 1 diagonal stripes at 250 m, 170 m and 100 m, respectively, along with a St. Andrew's Cross sign (analogous to North America's crossbuck) before the intersection.

Drivers reduced their speed significantly under all study conditions as they approached the crossing. Drivers approached the passive crossing at a slower speed than in the flashing-lights-off or the flashing-lights-off-and-gates-up conditions. However, the speed reduction observed at the passive crossing condition was not sufficient for about 30% of the cars to stop safely if a train was spotted. This was due, in part, to reduced visibility while approaching the crossing (Shinar & Raz, 1982).

Shinar and Raz noted that the passive condition ("Slow, signal out of order" sign) seemed to encourage drivers to approach at lower speeds than the non-activated active conditions. One explanation attributed the slowing in this condition to the sign that let drivers know the signals were out of order. It was believed that the indication of non-working signals indicated to drivers that they were responsible for looking for trains rather than relying on the signals. In the non-activated active conditions, drivers approached the crossing at higher speeds, which the authors suggested implied greater driver trust the active warnings to alert them to a train's approach. The authors further suggested that drivers slowed down in the activated active conditions because they did not completely trust the active systems to warn of a train's presence, otherwise drivers might not slow at all at active crossings. Shinar and Raz suggested that an improved active system would be one that tell drivers that the system is functional (e.g., operational status indicated by a green light) even when a train is not approaching.

In an investigation of 43 flashing light crossing accidents in Wisconsin and North Carolina, Berg et al. (1982) noted that in many situations where drivers chose to cross the tracks while the lights were activated, they did so when the lights were on for more than 30 seconds before the train arrived at the crossing. They suggested that motorists choosing to cross the tracks might do so because they become impatient with the long wait time. If drivers encounter these types of situations frequently, they may in fact begin to mistrust the signal system and instead use the presence or absence of a train to make crossing decisions. However, drivers are also likely to have habitual response patterns to crossing systems that are not at all governed by trust.

Ward and Wilde (1995b) examined the approach behaviour in daytime and nighttime conditions of drivers at a highway-railway grade crossing protected by flashing lights and bells (FLBs). The hypothesis tested was whether drivers were more cautious at night, perhaps because of reduced visibility or perceptual difficulties. An Automated Roadside Data Acquisition/Integration System was used to gather data at various points leading up to the crossing by using sonar pulses to measure vehicle speed. Two observers noted brake light activation as the vehicles drove toward the crossing. Activation was measured in seconds/metre (i.e., how many seconds the brake light was on and how far the car travelled). Data were acquired in two non-consecutive weeks from Monday to Friday during the summer. The periods of observation were from 6 p.m. to 8 p.m. for the daylight condition and from 10 p.m. to 12 a.m. for the nighttime condition. The study only observed single vehicles not in a stream of traffic and only included passenger cars, vans and trucks. Professional vehicles, vehicles with out-of-province plates and vehicles subject to special regulations (e.g., school buses) were not included.

Results indicated that the majority of drivers slowed as they approached the crossing whether it was day or night. Overall, drivers at night approached the crossing at slower speeds than drivers during the day. Although night drivers showed statistically significantly slower speeds when approaching the crossing, the actual difference between day and night speeds was marginal (day = 64.01 km/h, night = 61.79 km/h). There was no difference between braking patterns for day versus night drivers. However, drivers did show greater braking as they got closer to the crossing. The hypothesis that drivers are more cautious when approaching crossings at night was modestly supported. Only 20% of drivers applied their brakes when approaching the crossing, but most showed slowing patterns even without braking. Clearly, drivers slow down without braking by either gearing down or easing off the gas pedal; therefore, braking alone is not necessarily a good indicator of behaviour at crossings.

Ward and Wilde (1995b) did not discuss the odds of encountering a train at the particular crossing investigated, nor were drivers screened appropriately for familiarity with the crossing. The signals were not activated once throughout the entire study. Drivers familiar with the intersections during higher train traffic may have behaved differently.

Moon and Coleman (1999) sought to identify and compare the slowing behaviour of vehicles within groups or as single vehicles approaching a highway-railway grade crossing. In this study, two or more vehicles of any type close together constituted a group, and the data collected ranged from two to five vehicles in a group. As discussed, previous studies had found that individual drivers slow down when approaching crossings, but none had examined vehicles in a group or how group and individual behaviour may affect the specification of timing. Vehicles that approach a crossing are assumed to be approaching at a constant rate of speed, usually the speed limit. Moon and Coleman believed that the activation time of four-quadrant gates was too short to prevent vehicles from being trapped on the tracks between the gates. Design recommendation for four-quadrant gates is discussed in Section 5.

Two crossings on the Chicago-St. Louis high-speed rail corridor were used to gather data during busy periods of the day at two different times of the year (October and July). Data were gathered for both the morning rush hour and the evening rush hour to observe vehicles grouping together and their interactions as they approached the crossings. Single vehicles and vehicles in a group had consistent speed reductions. Vehicles that followed a lead vehicle frequently travelled slower than the lead vehicle. That is, following car speed was directly influenced by the lead vehicle's speed. Furthermore, vehicles travelling in a group averaged lower speed profiles overall than single vehicles. Moon and Coleman (1999) concluded that the timing of gates and lights at particular crossings might not be adequate to accommodate vehicular slowing, and suggested a longer time period for gates to lower.

Overall, single vehicles and groups of vehicles tend to slow down when approaching a highway-railway grade crossing. However, the reasons drivers slow may not be entirely evident. Decreases in speed as drivers approach crossings may reflect drivers' awareness of potential hazards ahead, such as the approach of a train. However, observations of slowing before a crossing do not necessarily imply the adoption of safe crossing behaviour by drivers. Shinar and Raz (1982) noted that in many cases the level of slowing that occurs may not be adequate to allow drivers to make appropriate manoeuvres should they encounter a train on the crossing or the activation of signals. Furthermore, as suggested by Moon and Coleman (1999) the timing of gates at active crossings may not appropriately accommodate the slowing behaviour of drivers at crossings, putting drivers at increased risk of becoming trapped on the tracks. Finally, certain factors such as long wait times may lead drivers to engage in riskier behaviour at crossings (Berg et al., 1982), such as slowing down to assess the situation and then attempting to cross ahead of a train that appears to be approaching slowly. Additional discussions of slowing behaviours at active warning signals can be found in Section 3.2.4.

3.2.3 Driver Behaviour at Passive Crossings

Lerner et al. (1990) and the NTSB (1998a) extensively reviewed driver behaviour at passive crossings and these reviews will not be repeated. Berg et al. (1982) investigated 36 accidents using accident reconstruction methods. Eighty-one percent of the accidents involved recognition errors, which were defined as a breakdown in the perception of information to a) recognize the presence or approach of a train and b) identify the available actions that would avoid a collision. Late recognition of a train was implicated in 19% of accidents. The primary contributing cause of recognition errors was limited quadrant sight distance. Trains already on the crossing were not seen because of darkness or because the alignment restricted viewing. Decision errors occurred in 18% of accidents. The principal contributing factor was inexperienced drivers or truckers travelling on slippery pavement. Crossings with high-volume or high-speed traffic in combination with low train speeds may have lead to either indecisiveness or risk taking.

3.2.4 Driver Behaviour at Active Crossings

Previous research indicates that accident frequency at flashing-light crossings is more than 10 times greater than that of gated crossings (Wigglesworth, 1979). The reasons drivers are at higher risk at flashing-light crossings versus gated crossings may stem from a variety of factors, including inappropriate signal timing (Berg et al., 1982; Abraham et al., 1998), lack of a physical barrier to crossing (Meeker et al., 1997), and general risk taking among drivers (Abraham et al., 1998).

Meeker et al. (1997) compared the results of a previous observational study of driver behaviour at a highway-railway grade crossing in Indiana to those of a new observational study at the same crossing after the installation of gates. The crossing previously had only FLBs, and cars were observed approaching the crossing when the lights and bells were activated but before the train arrived at the crossing. The crossing was approximately 20 m across, was elevated 1 m above the road, and had two adjacent tracks about 4 m apart. Observations were made during the day of drivers who arrived at the crossing after the flashers and gates had been activated but before the train arrived at the crossing. Observers videotaped the crossing as soon as the signal was activated, regardless of whether a vehicle was present. Four types of data were collected: whether the driver stopped or slowed perceptibly at the tracks; the elapsed time until a vehicle arrived at the crossing; the elapsed time during which the vehicle cleared the second track; and the elapsed time of train arrival at the crossing. The authors proposed two hypotheses: fewer drivers would elect to cross in front of the trains with the barriers present; and driver safety margins for violators in the gated study would be less than the safety margins for those who violated the flashing lights in the pervious study because a zig-zag manoeuvre was required to get around the gates.

In total, 60 vehicles were observed at the gated crossing. Thirty-nine were cars and 21 were trucks (i.e., mini-vans to dump trucks). The 1989 study (flashing lights only) collected observations of 17 trucks and 41 cars, for a total of 58 vehicles. In the gated study, 38% of drivers crossed despite the gates and lights. Of these, 17% stopped before proceeding and 30% slowed visibly. In the flashing-lights-only study, 67% of drivers crossed when the lights were activated, 36% stopped, and 51% slowed visibly before proceeding to cross. Fifty-two percent of drivers who crossed in the gated study did not stop or slow down before crossing, whereas only 13% of those who crossed in the flashing-lights-only-study did not stop or slow down before crossing. Similar observations of slowing behaviour at crossings have been previously reported (Shinar & Raz, 1982; Ward & Wilde, 1995b; Moon & Coleman, 1999). Insight into other behaviours at active warning devices is the strength of the Meeker et al. (1997) study. For example, drivers who crossed around the gates did so more often without either slowing or stopping than did the drivers who crossed in the flashing-lights-only condition.

There was no significant difference in safety margins between the drivers who chose to cross at flashing-lights-only versus gated crossings. Drivers in the flashing lights study seemed to exhibit more cautious behaviour. however, slowing down or stopping at a crossing and then making the decision to cross. As suggested by Berg et al. (1982), drivers may become impatient at flashing-light crossings and make the decision to cross ahead of the train after waiting for it to arrive for a certain period of time. Furthermore, drivers who cross around the gates may also do so because they do not want to wait for the train to pass.

Åberg (1988) observed driver behaviour at 16 different sites containing flashing lights and gates to identify specific driver "looking" behaviour. The focus of his research observed driver head movements at railway crossings within a 100 km zone around Uppsala, Sweden. Of the 16 sites observed during the research, 14 had flashing light signals, one had gates and, at one, crossing gates were being installed. The frequency of accidents at the 16 sites is not mentioned.

Driver head movements and visibility restrictions were observed at eight specific sites. All sites had only one track at the crossing. An observer was located on each side of the crossing. Two researchers made observations with an inter-rater reliability of $r = 0.81$. Of the 584 drivers observed in total, 349 (60%) made no head movements, 145 (25%) looked both ways, 59 (10%) looked in the direction where visibility was less restricted, and 31 (5%) looked in the direction where visibility was restricted. Significantly fewer drivers looked in the restricted visibility direction than in the less restricted direction (Åberg, 1988). Åberg suggested that drivers, if they do look, are more likely to turn their head toward the less restricted area and rely on the active crossing to provide information about train activity. Moreover, it may be easier to look in the less restricted direction, particularly when approaching on a road parallel to the crossing. While approaching on a parallel road drivers need no head movement to see an oncoming train (it will be almost directly in front of them), but an extensive head movement is required to look behind the vehicle. In fact, the occurrence of train-vehicle accidents is seven times higher when trains are approaching a crossing from behind the vehicle (Åberg, 1988). Thirty-three (69%) drivers were observed driving in both directions at the parallel crossing. Findings revealed that only 1/3 of these drivers looked behind them to check for a rear-oncoming train. For those who did not look, it was suggested that they completely rely on active warning devices to cue them about train activity. Åberg suggested that individuals who look in both directions were gathering redundant information to enhance the information provided by the train-crossing device, which is a hypothesis that lends support to Shinar and Raz's (1982) theory that drivers may not fully trust automated warning systems (also see Chugh & Caird, 1999).

Abraham et al. (1998) investigated 37 highway-railway crossing sites in Michigan to determine the extent to which drivers commit violations at crossings with active signal devices. The sites were categorized into four different groups. The first group consisted of 18 sites characterized by multiple tracks, a multilane highway crossing, gates, and flashing red lights. This group had the highest mean number of crashes for the seven years preceding the study. The authors noted that this was an interesting phenomenon, considering that these sites had the most protection in terms of signals and barriers. However, exposure rates were not discussed and, generally, crossings with more protection (e.g., gates) usually have higher traffic flows. The second group consisted of 6 sites with multiple tracks, a single-lane highway crossing (i.e., one lane each direction), gates, and flashing red lights. The third group of crossings included 8 sites with a single track, a multilane highway crossing, and flashing red lights only. Finally, the fourth group consisted of 5 crossings with a single track, a single-lane highway crossing, and flashing red lights only. Each crossing was videotaped for approximately 3.5 days for 2.5 hours each day.

Violations were categorized on a scale of 1 to 5, where 1 = routine (least hazardous), 2 = risky, 3 = more risky, 4 = severe and 5 = critical violation (most hazardous). For example, a routine violation occurred when a vehicle crossed more than 4 seconds after the train passed, but before the signals stopped. A risky violation was the same as a routine violation, but the vehicle crossed less than 4 seconds after the train passed. A more risky violation was when the vehicle crossed 8 to 10 seconds before the train arrived and the gates and lights were activated. A severe violation was the same as more risky, but the gates were completely down, or if no gates were present, the vehicle crossed with only 4 to 8 seconds of clearance before the train arrived. A critical violation occurred when the gates were down and the vehicle crossed less than 5 seconds before the train arrived, or if only flashing red lights were present, the vehicle crossed less than 4 seconds before the train arrived. Of the drivers observed who committed violations, 27% of driver actions were routine violations, 33% were risky violations, 19% were more risky violations, 19% were severe violations, and 2% were critical violations. Males committed 64% of the total violations and had the majority of violations in each category of violation severity.

Abraham et al. (1998) mailed out questionnaires to 820 drivers who were observed committing violations. Their licence plate numbers were used to locate their mailing addresses. Two hundred and seventy-six returned their questionnaires, which is a return rate of 33.7%. Of these, 68% said they used the crossing at least 4 times a week and 19% used the crossing 2 to 4 times a week. Most respondents said they ignored the signals or went around barriers because the "train was not in sight" or the "train was stopped for an unreasonable amount of time." Throughout the study, the police were never observed enforcing the traffic rules at any of the sites.

Based on these results, some drivers appear to be quite willing to violate an active signal and cross in front of oncoming train, possibly in an attempt to beat it (Abraham et al., 1998; Berg et al., 1981; Meeker et al., 1997). Berg et al. (1981) and Abraham et al. (1998) both attributed the timing of crossing signals as a reason drivers crossed when flashing lights were still activated. In the study by Berg et al. (1981), drivers were more likely to cross after the signal had been activated for more than 30 seconds. Unnecessary wait times were attributed to the presence of slower moving trains (e.g., freight) on track circuits designed to accommodate faster trains (e.g., passenger). Respondents to questionnaires in the study by Abraham et al. indicated that they violated the lights or gates because the train was not in sight or because it had been stopped for an unreasonable amount of time.

There are several inherent dangers when drivers make assumptions about the location or speed of an oncoming train and use those assumptions to violate crossing signals. First, restricted visibility may prevent drivers approaching flashing light crossings from seeing the train and they therefore erroneously assume that a train is not present. Second, if a train is stopped near a crossing with multiple tracks, the signals observed by the driver may actually be for another train approaching from either the opposite direction or from behind the stopped train on a parallel track. These types of accidents are called second train accidents. Third, drivers' judgments of how far away a train is from a crossing may be affected by perceptual factors, such as looming. The difficulties drivers have judging the oncoming speed and distance away of a train to a crossing are well documented (Leibowitz, 1985; Mortimer, 1988; NTSB, 1998a). For example, the 1986 NTSB safety study noted that passenger trains travel considerably faster than freight trains and that both types of trains often use the same set of tracks. This may cause drivers who are mostly familiar with freight trains to believe they can beat a train. Furthermore, Wigglesworth (1979) suggested that faster trains reduced the amount of time available to make a decision. Sixty-four of his 85 cases involved passenger trains versus slower moving freight trains. To have been included in Wigglesworth's (1979) study a fatality must have occurred. Passenger train impacts at higher speeds are more likely to result in driver or passenger fatalities.

3.3 Literature Review Summary

- Familiarity with a crossing influences driver behaviour in a variety of ways. Drivers familiar with crossings may violate traffic signals if they expect a long delay and possibly reduce their scanning behaviour to detect a train's approach.
- Overall, drivers, whether alone or in a group of vehicles, tend to slow on the approach to crossings. This slowing has been attributed to drivers preparing to cross an uneven track, to a lack of trust in automated warning devices, and to an intention to scan the track for trains. Differences in slowing patterns between night and day have not been adequately shown and only a slight reduction in nighttime speeds compared to daytime speeds has been recorded.
- The timing of gates and lights is often based on the road's speed limit; therefore, cars slowing at the crossing may not have enough time to cross based on the light's timing should they choose to cross. For example, vehicles that slow on approach to a four-quadrant gate and continue to cross are at risk of being trapped between the gates, depending on when the signals are activated.
- Passive crossings show an increased likelihood of recognition errors by drivers because drivers may simply fail to see trains at these types of crossings. Furthermore, obstructed sight lines are particularly hazardous at passive crossings because the ability to detect a train far enough away to stop is inhibited.
- Active crossings dramatically reduce recognition errors but produce other forms of driver behaviour error. Level of automation can induce violation behaviour when drivers are required to wait for a great deal of time. Overall, drivers exhibit a variety of risky behaviours at active crossings, such as going around gates or stopped vehicles (in the case of flashing-lights-only crossings).

4. HIGHWAY-RAILWAY GRADE CROSSING ACCIDENT CONTRIBUTORS TAXONOMY

4.1 Introduction

Error taxonomies have been developed in a number of domains ostensibly as descriptive and theoretic tools. A taxonomy may prove useful to a number of professionals depending on the question being asked (Senders & Moray, 1991). For example, it may aid in the understanding of common error-producing conditions or as a means to assign blame. Error taxonomies are less likely to aid in the assignment of blame *per se*, but are more likely to aid in the understanding of patterns of error and potential means to remediate frequently occurring error types. Consensus regarding a system of classification cannot always be achieved by either creators or users.

Error taxonomies have a number of limitations (Leveson, 1995; Meister, 1989; Rasmussen, 1990; Reason, 1990; Senders & Moray, 1991). These limitations include classification systems that are too fine-grained and yield too few meaningful classifications. Categories can also be too abstract or ill-defined to place accidents reliably into a given category. Categorizations are often singular and cannot accommodate many to one, many to many, or one to many causal connections. Databases impose their own constraints on classification systems and may not accommodate a variety of data types and relationships. Often the database is constructed without knowledge about how or why it will be queried. Addition and deletion of categories have multiple costs. Categories used in one database may have no relationship to categories (even with the same name) in other databases. Frequently, categories are used in place of the original accident details and this information is lost.

4.2 Identification of Factors

During the process of the literature review, the following items were identified as contributors to, data sources for, or outcomes of crossing crashes.

1. Track and road alignment
2. Condition of the roadway and tracks
3. Position and condition of signs and roadway markings
4. Crossing elevations
5. Weather conditions
6. Time of day
7. Time of year
8. Injury severity
9. Fatality
10. Property damage
11. Alcohol
12. Familiarity with crossing
13. Type of vehicle (car/truck/bus)
14. Age of driver
15. Train conspicuity
16. Train speed
17. Vehicle speed
18. Presence of driver distraction
19. Unsafe acts
20. Unsafe conditions

4.3 Taxonomy Description

Logical combinations of these factors, some of which overlap, yielded a taxonomy with several levels of categorization. The highway-railway crash contributor taxonomy is illustrated in Figure 4.1. It attempts to capture common contributors and multiple relationships among factors while avoiding a number of the taxonomic limitations previously described. The utility of the illustration is to guide in the selection of questions about physical, environmental, vehicular, and driver contributors. Elicitation of potential contributors helps to avoid omission of potential contributory factors. The purpose of creating a taxonomy of highway-railway grade crossing contributory factors is to highlight common patterns found across the literature reviewed.

The primary categories are unsafe actions, individual differences, train visibility, passive signs and markings, active warning systems, and physical constraints. The primary and secondary categories can be used to generate hypotheses about individual cases or aggregate accident data. Determination of why a crash occurs most often defaults to an examination of the actions and errors of the driver. These common factors are identified in the remaining categories.

Driving too fast when approaching a crossing, not looking to see whether there is an approaching train, or being distracted by internal and external objects are, by definition, unsafe acts. Driver behaviour before and during a crossing is, for some, quite risky. Each of the categories in the taxonomy allows investigators and researchers to posit potential accident contributors based on numerous prior studies. Drivers vary in their experience with advance warnings, their capability to detect and understand signs and signals, and their ability to accurately judge and decide on a correct course of action with respect to an approaching train. Furthermore, if drivers are impaired by drugs such as alcohol or by functional loss associated with disease or aging, their ability to detect, process, and act upon advance warnings is reduced. The capability to see a train and advance warnings can be impeded by the weather and lighting conditions (e.g., fog, rain, snow, night, driving into the sun). The alignment of the highway and tracks can also limit the visibility of trains, as can the presence of vegetation, buildings, and other visual obstructions.

Human factors is a broad field incorporating many disciplines. It involves the study of human behaviour (capabilities and limitations) as it relates to the design and use of systems and devices. While it is not possible to rank the six incident precursors in Figure 4.1 in order of importance as far as the contribution of human factors is concerned, it would appear that unsafe actions and individual differences are the most obvious types of human factors contributing to highway-railway grade crossing accidents. The former are largely a function of risk-taking behaviour and inadequate information processing by the vehicle driver, while the latter involve specific driver characteristics and capabilities that influence driver decision making and behaviour. Human actions (including driver limitations and impairments) and individual differences that interact with the roadway environment (including traffic control devices) come into play when one considers train visibility, physical constraints, and effectiveness of traffic control devices (warning systems, signs and markings). Human factors (driver action and capabilities) interact with these physical factors, including environmental conditions such as weather and darkness, to influence safety at crossings. In view of the evidence that up to 90% of roadway accidents involved human error or inappropriate behaviour as a contributing factor (Treat, et al., 1979), it is essential to understand driver perceptions and actions in examining safety at highway-railway grade crossings. A pure mechanical failure leading to a vehicle-train collision is less likely (e.g., see Treat et al., 1979).

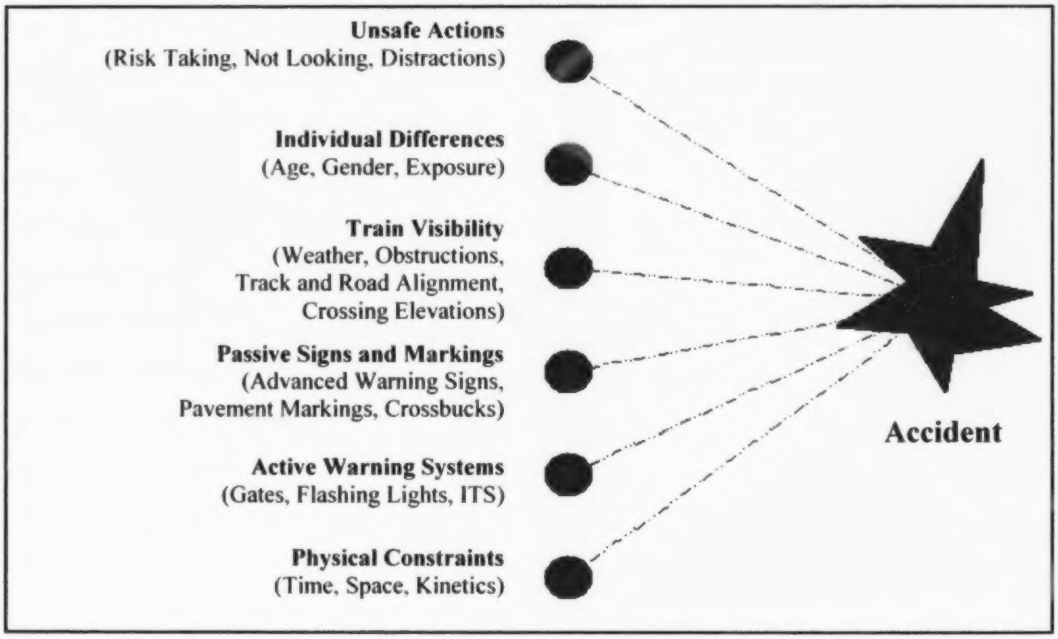
Unsafe Actions
(Risk Taking, Not Looking, Distractions)
Individual Differences
(Age, Gender, Exposure)
Train Visibility
(Weather, Obstructions, Track and Road Alignment, Crossing Elevations)
Passive Signs and Markings
(Advanced Warning Signs, Pavement Markings, Crossbucks)
Active Warning Systems
(Gates, Flashing Lights, ITS)
Physical Constraints
(Time, Space, Kinetics)
Accident

Figure 4.1 Taxonomy of highway-railway grade crossing accident contributors.

Active warning systems include gates, lights, and, in the future, ITS solutions. Warrants for gates and lights in Canada were described in Section 2. Traffic and train flow, number of tracks present, frequency of previous accidents, cost, and other design considerations determine whether active systems are installed at a crossing. The installation of gates to prevent forward travel across the tracks, accompanied by FLBs, is the most intensive intervention. FLBs without gates provide information about the approach of a train but do not constrain travel through the intersection. New designs of ITS, lights and gates are described in Section 5. The presence of either active (lights, gates) or passive (signs, pavement markings) crossing warnings can be defeated by drivers intent on crossing an intersection ahead of the train. The relative effectiveness of advance warnings is dependent on the driver's detection, understanding, and compliance.

Physical constraints such as time, space, and kinetics can be reconstructed, if desired, by accident reconstructionists. Doing so answers basic questions associated with where, when, and the outcome of train-vehicle collisions. Given the mass and stopping distance of trains, outcomes typically do not favour the vehicle, and train engineers have few options when a vehicle approaches a crossing on a collision path. Similarly, the friction of the roadway and track surface, which can be affected by weather conditions, affects stopping distance.

5. COUNTERMEASURES LITERATURE REVIEW

The purpose of this section is to review both contemporary and advanced technologies to reduce the frequency and severity of accidents at crossings. Countermeasures are grouped by intersection type (i.e., passive and active), modifications to the train, and ITS. Across all studies that were reviewed, determination of whether a specific countermeasure was effective was used as a primary screening criterion. The adequacy of the methods that were used was a secondary filter. Many studies failed one or both screening criteria. Parts of this review required a report that reflected the status of the research in the area, such as ITS, so some reports that failed to meet the criteria were included. A number of technical reports could not be obtained by the University of Calgary's Library Service or through the web. Thus, the studies that were reviewed are not necessarily comprehensive but are reasonably representative of each countermeasure type. Comparisons of countermeasure effectiveness and cost are discussed in Section 5.5.

5.1 Passive Crossing Countermeasures

The NTSB (1998a) identified a number of common safety issues associated with passive grade crossings, including:

- the adequacy of existing warning systems to alert the driver to the presence of a passive crossing and an approaching train;
- rail and track conditions that affect a driver's ability to detect the presence of an oncoming train;
- behavioural factors that affect a driver's ability to detect the presence of an oncoming train;
- the adequacy of existing driver education material regarding the dangers of passive grade crossings and driver actions required;
- the need for a systematic and uniform approach to passive grade crossing safety; and
- the need for improved signage at private passive grade crossings.

Solutions to these complex issues will require additional research on the effectiveness of existing countermeasures, policy and legal changes, and evaluations of new technologies. In particular though, current AWS's do not indicate to drivers whether crossings are passive or active. In contrast, signs in Europe, with some variance from country to country, do include an AWS that indicates whether the crossing is passive or active. The NTSB (1998a) recommends that the driver be told what to do—for example, to look both ways for a train and to slow to an appropriate speed—at the location of the AWS. Why AWS's have not changed for more than 50 years can be attributed, in part, to the practice of highway engineering.

One passive or active countermeasure is to provide lighting at the highway-railway intersection. Forty-seven rural intersections in Iowa were monitored after the installation of street lights at the grade crossing (Walker & Roberts, 1975). Accident data for the three years prior to and after the installation of lights were obtained and compared. No other changes were made at the intersections other than the installation of lights over the six-year period of investigation. Sunrise and sunset information throughout the state was used to determine whether an accident occurred at night or during the day. Overall, 90 nighttime accidents occurred at the 47 intersections in the three years before lighting was installed. After installation, 46 nighttime accidents were recorded, a reduction of 49% in accidents. This occurred despite an average increase of approximately 11% in roadway traffic between the two periods. When the change in traffic volume was considered, the reduction rate rose to 52%. In contrast, no significant change in daytime accidents occurred over the six-year period for the before and after conditions.

The greatest reduction in night-time accidents occurred at intersections that had an average daily traffic volume (ADT) of 3,500 vehicles or more. Other data showed that there was no difference in accident rates depending on the number of street lights present at a crossing. No more than five lights were present at any crossing.

The need to warn pedestrians and vehicles of a second train is well known within the light rail transit (LRT) transportation research community (Korve et al., 1996). Khawani (2001) provides an update of an ongoing project to evaluate the effectiveness of a second-train warning system for the Los Angeles County LRT system. A site was chosen where several accidents between trains and pedestrians had occurred and where the geometry of the crossing made detection of a second oncoming train by pedestrians difficult. Two trains passed each other at or near this crossing approximately 15 to 20 times per weekday. A panel of transportation safety specialists met to suggest and design several types of warnings. Interviews were then conducted near the crossing to determine user preference and understanding of the message to be conveyed (i.e., that a second train was approaching on the opposite track).

The sign that was evaluated was a two-sided fibre-optic sign 3 ft. high and 4 ft. wide that was placed 7 ft. above the sidewalk. The sign was activated by a trigger in the track circuit and alternated between showing a train on the left with an arrow pointing to it and showing a train on the right with an arrow pointing to it to indicate two trains approaching. Educational materials were distributed in the neighbourhoods where the sign was located. Posters and flyers were used to try to ensure pedestrians knew the sign would be installed and what it meant.

The preliminary data showed that fewer pedestrians entered the track area during a two-train event after the installation of the prototype sign. Pre-installation data were collected from March 24 through June 9, 2000, and post-installation data were collected from July 30 through September 15, 2000. Before the sign was installed, approximately 379 pedestrians entered the track area 15 seconds or less before a second train entered the crossing. After installation, an average of 108 pedestrians entered the track area 15 seconds or less before a train entered the crossing. As well, before installation, approximately 64 pedestrians entered the track area 6 seconds or less before a train entered the crossing versus 14 after installation. However, these reductions should be interpreted cautiously because 1,353 two-train events occurred in the before-installation time period and only 755 occurred in the after-installation observation window. Furthermore, it is unknown whether seasonal variance affected the number of pedestrians using the crossing in these two different data collection time periods. The reduction in pedestrians entering the crossing could be due to fewer pedestrians using the crossing in the summer than in the spring. Additional after events need to be collected to balance the before and after conditions.

This warning system was specifically designed for an LRT system in an urban area and does not necessarily translate to train crossings with lower train traffic, such as passive rural crossings. However, for busier crossings in urban settings, perhaps especially where a freight line runs adjacent to an LRT system (e.g., Calgary), it may offer insight into developing prototype warnings for pedestrians and drivers at this type of crossing. Active signs, just like flashing lights and gates, are more expensive than regular signs, and the costs and benefits of such a system would have to be evaluated.

Hanafi (1997a) reviewed second-train warning systems in different countries and evaluated whether they meet the following criteria for alerting pedestrians that a second train is about to arrive:

- System displays a clear message or signal that a second train is about to arrive.
- Sign or signal is displayed only when a second train is approaching the crossing.
- Second-train warning is distinguishable from the warning for the first train.
- Warning is targeted for pedestrians.

Although this report describes in detail the technical aspects of the second-train signs and signals, neither this report nor the operators of the systems reviewed have made an analysis of their effectiveness. At some of the crossings no accidents occurred either before or after installation, which makes comparison of accident rates impossible.

The capability of drivers to adequately understand traffic signs and signals prior to and at highway-railway grade crossings is a long known problem (Richards & Heathington, 1986; NTSB, 1998a) and has received recent research emphasis (Lerner, 2002). AWS's provide little useful information other than to indicate the presence of a crossing (Mortimer, 1988). Signs that indicate whether the type of crossing is passive or active would be useful. Symbolic signs that are adequately tested for comprehension may also prove useful. Designs such as the Canadian crossbuck (Ells et al., 1980) can significantly improve perception-response time (PRT) and legibility, if adequately tested.

A number of optional and supplementary devices have been used at grade crossings to enhance the safety. For example, in 1993 Australia introduced the optional use of a red target board (the crossbuck on a rectangular red background panel) to improve visibility of these signs where increased conspicuity is required. In some countries (e.g., Australia, Israel, U.K.) drivers are informed about distances to the crossing with supplementary signs. In addition, the presence of active warning signals is indicated with a unique AWS. Some countries (e.g., Australia) also provide supplementary information at certain crossings with "trains cross here", "look for trains", "stop" and "give way" (yield) signs. It would be helpful, especially at passive crossings, to indicate that the tracks are clear (no train approaching). This is done in Sweden with a white light at the crossing. The use of reflective tape on crossbuck signposts helps detect a crossing's presence at night as it creates a "shutter effect" by the crossing train when seen between rail cars with headlights shining on the back of the post. Reflective material should be not too high to allow retro-reflection back to the driver. The use of retro-reflective sign materials has been investigated in Canada (Hanafi, 1997a).

Drivers need to determine whether a crossing has active or passive protection to know the degree of their responsibility for detecting trains. One advantage at passive crossings is that it takes longer to detect the absence, rather than the presence, of a train. About 20% of drivers think all crossings are active (Richards & Heathington, 1986), so they interpret the absence of a signal as indicating no train.

Drivers do not always understand the meaning of warnings. For example, a flashing red signal in most traffic applications means stop, then proceed with caution. Some drivers view flashing lights as advisory requiring them only to slow, not necessarily to stop. Such an interpretation of a flashing highway-railway crossing signal could lead to an accident.

The use of stop signs at passive highway-railway grade crossings has been the subject of extensive debate (Mortimer, 1988; NTSB, 1998a). Sixty percent of drivers stop at stop signs at passive highway-railway crossings, compared to 80% at highway-highway intersections (Parsonson & Rinalducci, 1982). A research project is underway by Transport Canada to study truck peformance at crossings and a proposed regulation is being considered. Acceleration of trucks and buses from a dead stop across a number of tracks is also a known problem (Kendall & Morrisette, 1995, May; Mortimer, 1988). The NTSB has concluded that a stop sign should be placed at highway-railway crossings (NTSB, 1998a). The overall level of safety at passive crossings is expected to be improved through the installation of stop signs.

5.2 Active Crossing Countermeasures

Traffic control devices are used extensively (at least some at virtually all crossings) to warn of the presence of the tracks, and sometimes of trains as well.

Recommendations to enhance safety at crossings include:

- indications of speed advisory;
- floodlights activated by an approaching train to light up the crossing and increase its visibility and alert drivers;
- in-vehicle warning systems to alert drivers that a train is coming; and
- a warning horn located at the crossing and activated by the approaching train.

A number of these solutions have been evaluated.

A comparison of 1,552 grade crossings in California prior to and after the installation of automatic warning devices between 1960 and 1970 was made (Schulte, 1975). Warning devices included either flashing lights (434 crossings) or automatic gates (1,118 crossings). Over the 10-year period, both devices showed a reduction per crossing-year of 69% in vehicle-train accidents, 86% in deaths, and 80% in injuries. Reductions for crossings with gates showed a vehicle-train accident reduction of 70%, a reduction in deaths of 89%, and an 83% reduction in injuries. Accident rates were lower for rural intersections than for urban intersections, but the reduction in all accident and casualty rates was higher for rural intersections. These statistics do not take into account traffic volume (for either vehicles or trains) and should be interpreted cautiously.

Schulte (1975) discussed the importance of considering not only accident frequency but also accident severity to determine the economic benefits of installing automatic warning systems.

The incidence of drivers disobeying traffic laws and running flashing lights and gates was addressed. In 1973, there were 2,197 vehicle-gate accidents, whereby a vehicle collided with a gate or was hit by a gate coming down. Gate accidents may indicate driver inattention or distraction at crossings, or perhaps some drivers misunderstand how to approach a gated crossing. This paper provides good background information on the effectiveness of active crossings. It also addresses the cost of installing gates and suggests that lights and gates be considered for high-volume, high-risk intersections, where the cost-benefit trade-off is best.

Noyce and Fambro (1998) attempted to determine the effect a vehicle-activated strobe light on directing drivers' attention to passive rail signs such as crossbucks and AWS's. In addition, the authors investigated whether the additional sign caused drivers to respond more cautiously to the presence of a highway-railway grade crossing. The strobe light was located on top of an enhanced sign—an AWS with an additional sign underneath that read "look for train at crossing"—located 17 m from the crossing. A crossbuck was also located right before the crossing. A detector 170 m from the AWS tripped the strobe light, activating it for approximately 8 seconds.

A before-and-after speed study showed that on the westbound approach, after speeds were lower than before speeds, especially around the warning sign and as drivers entered the non-recovery zone at approximately 100 m from the crossing (Noyce & Fambro, 1998). Average speeds on the eastbound approach did not change significantly at the beginning of the non-recovery zone at 100 m. Average speeds on the approaches were lower after the installation of the sign. However, despite some statistically significant differences, actual speed differences were small, about 2 to 3 km/h slower in the after condition.

A driver survey was used to determine whether drivers' attention was being drawn to the strobe light (Noyce & Fambro, 1998). Eighty-two percent of drivers surveyed (N = 33; 23 male, 10 female) indicated that they used the crossing regularly. Fifty-two percent of drivers indicated that they had noticed something either unique or different about the grade crossing, which is a higher rate than shown in previous studies where only about 20% of drivers were able to recall standard railway warning signs. Of the 17 drivers who noticed something unique or different, 15 saw the strobe light and 12 saw the supplemental sign. Of all drivers, 21 out of 33 observed the strobe light. Nineteen drivers said they used additional caution, which included slowing down, reading the signs, looking for trains, or stopping at the crossing when they saw the strobe light. The other 14 did not change their behaviour, mainly because most did not see the strobe light. Eight respondents thought the strobe light meant use extra caution at the crossing; 3 thought it meant they should reduce their speed, and 8 believed that the light meant pay attention, be careful, read the signs, or look for a train. None of the drivers said they thought the strobe meant a train was approaching. However, the sample size for the survey was low and the results may not necessarily be replicated in a larger group.

Eighteen drivers observed the supplemental sign and 11 of those were able to recall the words exactly or a recall very similar wording. A driver observation study revealed that drivers did not react adversely to the onset of the strobe light. The only changes in behaviour observed were braking in the vicinity of the sign and strobe.

The strobe light appears to have had the desired effect of getting more drivers to read the signs and exercise caution at the passive crossing. Furthermore, the study reported that the strobe light was most visible during night conditions compared to day or dusk. Future research may show that the strobe light is a better nighttime countermeasure and that other options for passive crossings should be considered for daytime conditions. The effectiveness of the strobe over time needs to be addressed. Familiar crossing users may no longer attend to it over time. The novelty of it may wear off.

A field study of six different types of crossing systems was conducted by Heathington et al. (1984). The systems included:

Four-quadrant gates without skirts (A).
Four-quadrant gates with skirts (B).

Four-quadrant flashing light signal without overhead strobe lights (A).
Four-quadrant flashing light signal with overhead strobe lights (B).

Highway traffic signal system with one white bar strobe light (A).

Highway traffic signal system with three white bar strobe lights (B).

These systems were tested to determine whether A or B for each type was preferred over the other by participants and whether one group of systems (1 vs. 2 vs. 3) was preferred over the others. As well, each group was tested with different signal actuation distances (null = 0 ft., long = 670 ft., medium = 440 ft., and short = 330 ft.) and all systems were tested in day and night conditions.

All six systems were perceived by participants to be better than the standard warning device used at crossings. The comparison standard warning device was not described. In both day and night conditions, the four-quadrant gates with skirts were perceived to be the most effective warning device, followed by four-quadrant gates without skirts, four-quadrant flashing lights with overhead strobes, highway traffic signals with three white bar strobes, and highway traffic signals with one white bar strobe. The four-quadrant flashing light signals were perceived to be the least effective signal device.

Brake reaction time and maximum deceleration rate were also analyzed to further describe participants' reactions to the different devices. There was no significant difference between the gate systems and the flashing light systems, but there was a difference at 440 ft. between these two systems and the highway traffic control signal systems. At the medium actuation distance, responses to the two gated systems were faster than responses to the other four systems, but there was no difference in response times between the two gated systems (skirts vs. no skirts). Responses to the gated system with skirts were always the fastest of all six systems. At all actuation distances, the two types of highway traffic control signal systems yielded the slowest responses times overall.

Heathington et al. (1984) is an older study and four-quadrant gates are still too expensive to have garnered widespread use. However, the four-quadrant gate could be very effective for high-volume crossings, as suggested by Moon and Coleman (1999). Their findings of vehicle slowing profiles suggested that activation times for four-quadrant gates need to be increased. For active crossings with lights, perhaps a four-quadrant traffic light could be more effective than the two-quadrant systems in use some places; however, cost is still an issue. The finding that people preferred the strobe light condition of the flashing light system adds some weight to the use of a strobe light to draw further attention to signals at crossings (both passive and active). Finally, this research does not suggest any changes for passive crossings as cost still limits the use of lights and gates.

The findings of studies in which drivers were found to slow significantly when approaching a crossing suggest that the design of signals and gates may not be appropriate for actual behaviour that occurs at crossings. Moon and Coleman (1999) suggested that groups of cars slowing at a four-quadrant gated crossing that is timed based on the speed limit might result in vehicles becoming trapped on the crossing because the timing does not accurately reflect the behaviour of the traffic. Moon and Coleman (1999) recommended an increase in gate time of about two seconds for four-quadrant gates for each of the crossings investigated in their study to prevent drivers from becoming stuck on the tracks.

Gate warning time is critical. Long waiting times invite violation behaviours. For example, if a passenger train is travelling at 70 mph (113 km/h), it provides a 30 second warning, where a slow moving freight train travelling at 35 mph (56 km/h), gives a minute long warning. In the presence of congestion, getting stranded between the gates is another concern. Obstruction detection would allow the gates to rise if a vehicle is trapped on the tracks. With these constraints in mind, the "School Street System" was installed in Groton (West Mystic), Connecticut (Hellman & Carroll, 2002). It is a four-quadrant gate, obstruction detection system. Advance warning times were between 65 and 79 seconds depending on train travel direction. Annual ADT volume was 900 vehicles. About 15 to 20 train movements occurred daily.

A before-and-after assessment of a two-gated crossing and the new four-quadrant gate was conducted by Hellman and Carroll (2002). Baseline data for the two-gate system were gathered using video-based monitoring from July 1997 to August 1998, and the four-quadrant gate was observed from January 1999 to October 2000. Difficulties with construction during the baseline period substantially reduced the sample size. The principal dependent variables were Type I and

Type II violations. Type I violations were defined as those where drivers crossed the intersection between when the warning lights came on and when the gates were completely lowered. Type II violations were defined as those where the driver drove around or through the gates.

Each violation type was computed based on accidents per 100 train movements. Type I and II violations were reduced by the installation of the four-quadrant gate system. In addition to the total number of violations of both types being reduced, the number of Type II errors (i.e., driving around the gates) was reduced to 0 within the observation period. Seasonal analysis seemed to indicate fewer violations during peak traffic flows (i.e., summer). Longer traffic queues may prevent violations. In months where flow and queues were lower (i.e., fall and winter months), the highest average violation rates occurred. The reliability of the four-quadrant gate system is important because vehicles can be trapped on the tracks if system failures occur. The operation of the four-quadrant gate system performed well and required few post-installation modifications.

As one phase of a four-phase large-scale program, Carroll and Haines (2002a) summarized the effectiveness of a range of countermeasure treatments along North Carolina's "sealed corridor". Fifty-two highway-railway grade crossings were either closed, grade separated (bridge or overpass), or photo-enforced (i.e., digital ticketing). On other intersections four-quadrant gates, long-arm gates, or median barriers were installed. Additional signs and pavement markings were added to all treatments.

Preliminary risk analyses, which compare five-year historical fatalities from the Federal Railroad Administration's (FRA) database with those observed since installation, indicate the potential for lives saved is approximately five. Prior to the treatments 19 fatalities from 14 crashes occurred at the 52 crossings. All but one of the crashes occurred when drivers drove around or through gates. The economic cost of the treatments for "lives saved" yielded a 40:1 return ratio (i.e., $15,614,100 to $400,000, respectively). The effectiveness and cost of specific treatments can be found in Table 5.1.

5.3 Train Countermeasures

These countermeasures include devices on trains such as oscillating headlights, strobe lights, and reflective markers. Standard headlights, located about 4.5 m above the tracks, provide about 200,000 to 250,000 candela, and are spread about 10° vertically and horizontally. The centre of the beam strikes the track about 242 m ahead. Carroll et al. (1995) investigated the effectiveness of auxiliary train lighting systems in warning drivers of an approaching train. All the lights investigated in this study are in use by the railway industry. All but two types of strobe lights in use exceeded the 1993 and 1994 FRA Interim Rule requirements for intensity. The standard train headlight alone was the control condition. The headlight alone was compared to the use of the headlight in combination with either ditch lights, which were angled 15° outward from the train; crossing lights, which were on the centreline of the train; or strobe lights, which were mounted on top of the train. The lighting systems were compared based on relative effectiveness. That is, the light that was observed at the farthest distance in the study may also be observed at the farthest distance under actual driving conditions. However, it might not be observed as far away from the crossing in actual driving conditions as it was in the study due to the fact that participants in the study were expecting a train, whereas a normal driver might not be. A 50% reduction in detection distances in a real-world setting could occur.

The three independent variables were locomotive approach direction, ambient light level, and type of alerting system. Ambient light level was a between subjects variable, and alerting light system and locomotive direction were a within-subjects variable. Train speed was held constant at 45 km/h. The two trains had different paint patterns to see whether paint pattern or lights had a greater effect on daytime detection.

The field test site had a crossing angle of 90° with an unobstructed view left and right from the observation point on one side. The 90° angle of the crossing and good visibility to either side may limit the application of these data to crossings with different angles. Participants were seated in chairs 62.5 m from the crossing. They were asked to perform a visual monitoring task in which they viewed arrows displayed on a screen located 2 m in front of them. They responded to the presentation of either an up or down arrow by pressing the corresponding arrow button on a keyboard. The purpose of the visual monitoring task was to focus attention forward and to simulate the actual demands on attention experienced while driving. Participants were encouraged not to look left or right, but to indicate when the train was visible in their peripheral vision and what direction it was coming from. They were then asked to estimate the time of arrival at particular points along the track. Participants wore headphones to eliminate auditory cues that might indicate the direction the train was approaching from. Because the observers were stationary, the detectability and arrival time estimates may be different for drivers approaching an intersection in their vehicle. The researchers acknowledge that many drivers approaching a crossing may not expect a train and that, therefore, detectability distances would be smaller than those found in the study.

A main effect was found for locomotive approach direction, which was unexpected because trains approaching from both sides were intended to control for expectations. Further investigations indicated that the lighting systems on the left locomotive were powered by a battery because of a generator failure. Therefore, the voltage produced was lower than the required 74 V needed to properly power the lights, which meant the intensity of the left locomotive lights was lower than that of the right. Left locomotive data were excluded from the rest of the discussion. Only results collected for the detectability of the right locomotive were analyzed.

Observers detected the trains when they were farther away from the crossing in the night condition. The mean detection distance was 468 m for the night condition and 364 m for the day condition. For day and night conditions, the headlight and crossing light combination was observed the greatest distance from the crossing, followed by the headlight and ditch light combination, the headlight and strobe light combination, and the headlight alone condition. The crossing light system was significantly different from the ditch light, strobe light, and headlight alone conditions. The ditch light system was different from the headlight alone condition, but not the strobe light condition. The difference between the strobe light system and the headlight alone condition was minimally significant. Observers also reported that the lights were the first thing they saw in both the day and night condition.

Observers overestimated how far the train was from the grade crossing for all alerting systems. However, observers tended to underestimate arrival time in the 7-second interval condition. Accuracy in arrival time was measured by how close the judgment was to 100%. Overestimation of distance was smallest for the ditch lights (101.5%), followed by the crossing light (104.7%), strobe light (108.1%) and headlight alone (117.9%) conditions. However, the differences were only significant for the ditch lights versus the strobe lights and the ditch lights versus the headlight alone. For all conditions, as the arrival time interval being estimated increased from 7 seconds to 22 seconds, judged arrival time went from underestimation to overestimation. Arrival time judgment was 89.2% for the 7-second interval, 108.2% for the 12-second interval, 114.9% for the 17-second interval, and 120.4% for the 22-second interval. The crossing light system yielded the lowest number of estimation errors across all time intervals. The overestimation of times in the 12-, 17- and 22-second interval conditions means that drivers may put themselves at risk if they decide to cross the tracks. Overestimation at the further distances could be because it is difficult to perceive changes in velocity as a vehicle approaches head on.

There was no difference between the day and night condition for arrival time estimates. The researchers suggest no differences were seen between day and night because the lighting systems provided the stimulus by which the trains were detected, rather than other features, such as paint pattern. Observers said that the lighting systems were what they saw first to detect the train in both the day and night condition, but it is unknown what cues observers used to estimate arrival time in the day and night conditions. In daytime, drivers could use the visibility of the train compared to other features in the landscape in combination with the lighting system to estimate arrival times. At night, drivers could usually only see the lights of the train and not the surrounding features, which might have made estimation time more difficult because they only had a single source of information to use for estimation. However, this does not explain why no difference was seen in the study between day and night. The small sample size (9 day observers and 14 night observers) for the between-subjects comparison of day and night may have limited statistical power. Some observers indicated that the ditch light system blinded them for a period as the locomotive passed.

To determine whether the different systems actually reduced the number of accidents at grade crossings, the researchers compared accident rates from before the installation of lighting systems on trains to after their installation. Four different railways agreed to participate by providing accident data, but the data available were limited and no strong conclusions about the effectiveness of the systems at reducing accidents could be drawn from this study. However, the initial data suggest that the auxiliary lighting systems have the potential to reduce the rate of accidents at grade crossings. Furthermore, the cost and maintenance of such systems appeared feasible for most rail companies.

Carroll et al. (1995) summarized a variety of findings regarding auxiliary alerting light systems from various countries, such as the U.K., Canada, and Australia. Canadian ditch lights are different from U.S. ditch or crossing lights in that Canadian ditch lights actually cross each other at 45.8 m horizontally and hit the opposite track at 92 m. U.S. ditch lights and crossing lights do not cross each other in the horizontal plane. Australia uses a "cross-eyed" system as well, and Dunn, Hewison, et al. (1992, as cited in Carroll et al., 1995) report that the crossed lights were easier to detect and did not blind the observer at various distance/inclination combinations. Because the Canadian system is different from the U.S. systems, extrapolation of results from this study to Canadian trains is difficult. However, because this study showed that similar auxiliary alerting systems in combination with the standard headlight were better detected than the headlight alone, it could be suggested that the Canadian system is probably more effective than the headlight alone condition. The Canadian standard was implemented after a derailment in 1974 when a train ran into a landslide on the tracks at night.

Using a low-fidelity driving simulator, Multer et al. (2001) investigated the degree to which drivers can recognize reflectorized freight cars versus non-reflectorized freight cars in a highway-railway grade crossing at night, when both the car and the train are moving. They also investigated whether drivers had difficulty discriminating reflectorized rail cars from other objects, such as trucks or cars, in an intersection. In Canada, freight cars less than 50 ft. long are required to have four reflectors per side and six if longer than 50 ft. The tape, if kept clean, is likely to increase the conspicuity of trains when train visibility is limited, such as at night.

A signal detection task was used in the first experiment to determine the extent to which drivers could tell trains from trucks based on the reflective patterns on each. Larger trucks in the U.S. are required to have reflectorized markings and one purpose of this research was to see whether motorists confused the patterns used on trucks with those used on trains. Four patterns of reflectorization (horizontal bars, vertical bars, massed outline, and variable vertical bars) were tested on two types of rail cars, a hopper car and a flat car. The four truck patterns (all horizontal patterns with different numbers of reflective strips presented) authorized by the U.S. Department of Transportation were tested on a truck. Non-reflectorized rail car and truck conditions and signal absent conditions were also included in the trials. Participants viewed 1200 trials (half in a rural setting and half in an urban setting) of a 90° intersection where either a train or a truck, could cross and decided whether they saw a train, a truck or nothing in the intersection on each trial.

There was no significant difference in discriminating between trains and trucks based on the reflectorized pattern used. Participants found it harder to detect non-reflectorized freight cars in the rural (85% accuracy) versus the urban (92% accuracy) environment. Based on participants' self-assessments of their own confidence in their decisions, participants varied in their willingness to say a train was present or absent in the urban condition.

The second experiment investigated the recognition distance for each pattern type on freight cars and calculated the recognition errors (e.g., saw train but indicated they saw truck). The reflectorized freight cars were identified at greater distances than the non-reflectorized freight cars. The larger hopper car was identified at greater distances than the low-lying flat car (1,026 ft. vs. 947 ft.). The vertical bar pattern was recognized best for both the hopper and the flat car. The horizontal bar pattern and the outline pattern were more likely to be confused with a truck than the variable vertical bar or vertical bar patterns. Recognition errors were lowest for the vertical bar pattern.

Although this study replicated some findings of previous studies, such as reflectorization increases the distance at which drivers can see a freight car, there are limitations due to the methodology used. A low-fidelity driving simulator was used to simulate nighttime conditions, but no indication of the patterns' actual luminance or intensity as would occur in the real world or within the simulated world is mentioned in the study. The luminance and intensity of objects projected on a screen could vary greatly and may not adequately address actual lighting conditions as they occur at a grade crossing. The study does not include calculations for determining how much ambient light is present at the crossing (either from headlights or lights in the environment), even though they indicated use of an urban and rural setting. However, the study does make some suggestions for choosing a standard pattern for rail cars: most simply, that they should be distinct from those used on trucks, which should be obvious. The capability of a low-fidelity driving simulator to adequately generate "similar enough" lighting conditions is highly suspect. The impact of this limitation on detection distance and accuracy should not be underestimated.

5.4 Intelligent Transportation Systems

Richards and Bartoskewitz (1995) outlined possible applications of new technologies to improve the effectiveness of warning motorists of the approach or presence of a train at a highway-railway crossing. Previous problems with integrating highway and railway safety have been the result of poor communication between the railways and highway authorities (e.g., neither gives the other adequate information regarding traffic flow). Both the architecture of ITS and the Advanced Train Control System (ATCS) can be used to increase the communication between highway and railway systems. For example, Advance Vehicle Safety Systems, which include longitudinal collision avoidance, lateral collision avoidance, intersection collision avoidance, and vision enhancement for crash avoidance, can be integrated to use ATCS information to predict where trains are and communicate the location to drivers (although drivers may use this information to beat trains to crossings).

ATCS itself is a microprocessor/communications/transponder-based system designed to provide both safety and business functions for rail. It is a joint program of the Association of American Railroads and the Railway Association of Canada. Its safety benefits can include such things as enforcement of authorized operating speed limits, transmission of track occupancy/movements to trains and acknowledgements from crews via digital communications systems, and protection for maintenance-of-way and other workmen on the tracks.

Some suggestions for integrating ITS and ATCS involve the use of Global Positioning Systems within the system architecture to warn approaching motorists of a train's proximity to the crossing via an In-Vehicle Warning System. Such things as automated horn systems, which provide an audible warning of constant intensity to motorists, and improvements in crossing illumination to increase the visibility of trains at night are considered to be low cost and of minimal complexity to implement. Vehicle Proximity Alerting Systems for specific vehicles (e.g., school buses, large trucks, hazardous materials haulers, emergency vehicles) for use at passive and active crossings to indicate a train's presence is considered to be of intermediate cost and technological complexity. Intrusion detection (video image processing of stalled, disabled or trapped vehicles blocking crossings) and dynamic displays that tell a driver what to expect at a crossing (e.g., "train approaching from right/left" and "number of seconds to arrival" messages) are considered to be high cost and complex. None of the technologies discussed were evaluated.

Chugh and Caird (1999) assessed the potential of an in-vehicle train warning (ITW) presented in a head-up display (HUD) to convey highway-railway advance warning information. In addition, the effect of the reliability of the system on driver response time and trust was assessed. Thirty-six participants ranging in age from 18 to 26 years volunteered for the study. On average, participants drove about 15,000 km per year. A modified rail AWS was presented as a HUD overlaid on digitized driving films (see Figure 5.1). Using a low-fidelity driving simulator, participants responded to a limited number of events by using a steering wheel, brake, and accelerator pedal. For example, the participant could use the pedal and accelerator to achieve three film speeds that mimicked hard and soft braking and accelerating. Digitized driving films were projected 3.5 m in front of the participants onto a screen. A total of eight highway-railway grade crossing approaches were filmed. Each crossing was filmed in summer and winter conditions, yielding a total of 16 two-minute films. Clanging bells were added to the sound track as a driver approached a crossing. The ITW was presented for 2.5 seconds about 10 seconds prior to each highway-railway crossing.

To determine reliability effects on behaviour, participants were randomly assigned to either 50% or 83% reliability condition. Type of failure was also manipulated within-subjects. The ITW was presented when no crossing was present (i.e., false alarm) and not at all before a crossing (i.e., missed signal). Each participant "drove" a total of 24 video sequences. Each sequence consisted of an approach to a railway grade crossing intermixed with driving through urban and suburban traffic environments. Participants were instructed that the ITW informed them of a potential approaching train. All participants were instructed to drive normally and to slow down for railway grade crossings.

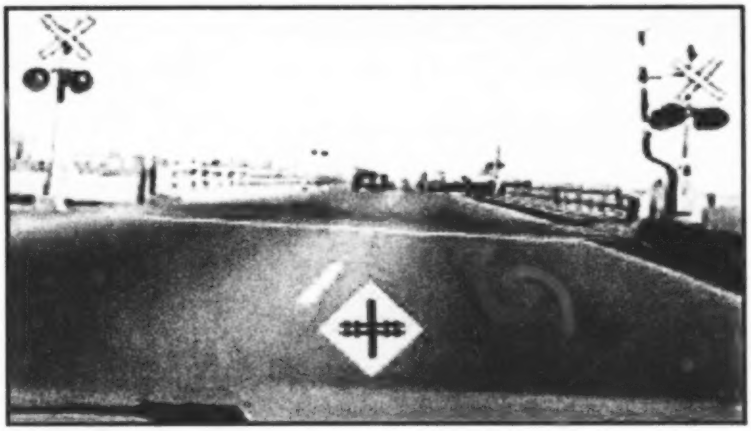

Figure 5.1 Head-up display of in-vehicle train warning used in Chugh and Caird (1999).

The average PRT to the ITW display was 1.75 seconds, which was stable over the first two baseline measured blocks. When drivers were warned, but a train failed to appear at the crossing (i.e., false alarm), PRT significantly increased. In addition, those participants exposed to the false alarms also braked later as they approached crossings. The effect of reliability on PRT was to increase it and more so when the reliability of the signal was less (i.e., 50%). Interestingly, for the last two critical events 4.2% of participants failed to respond to the ITW after experiencing the false alarms. Moreover, in the 50% reliability group, after experiencing false alarms, 6.9% of participants did not respond to the ITW. Measures of trust decreased depending on the reliability of the ITW system, more so for those in the 50% reliability group.

ITW can provide a means to increase a driver's detection and decisions about approaching highway-railway grade crossings. At crossings where limited sight lines reduce the likelihood that crossings can be detected, ITW may be one means to provide redundant information about an approaching crossing. The reliability and the way failures occur when using an ITW may cause drivers to ignore the technology. Participants tended to adjust to unreliable ITW information by increasing their scanning of the traffic environment and developing a mistrust of the system. The use of in-vehicle technologies to aid the driver has a number of human performance advantages and disadvantages (e.g., see Caird et al., 2000). For example, presenting an ITW on a consistent basis may produce an over-reliance on the technology, and drivers may no longer adequately scan the traffic environment for trains and other hazards. Practical constraints, such as cost of deployment and the uniform integration of in-vehicle technologies, currently limit ITS technologies.

5.5 Countermeasures Summary

A number of seminal reports comprehensively summarize the status of many countermeasures efforts (e.g., see Carroll & Haines, 2002b; Lerner et al., 1990; NTSB, 1998a). The time and scope of this project prevented an extensive audit of all available countermeasures and their relative effectiveness. The utility of this review is to integrate reports and literature previously unreviewed and to provide a means to compare treatments. Strategic resource decisions require cost effectiveness information. In addition, gaps in countermeasure effectiveness and evaluation become immediately apparent. Collapsing the subtleties of why, when, where, and how the countermeasures should be implemented into simple conclusions does not tell the entire story. The methods by which countermeasures are evaluated and why they were chosen in the first place are important.

Organized by countermeasure age, Table 5.1 presents information on countermeasure effectiveness and cost. The literature source of the effectiveness and cost information is also given. The relative effectiveness of a given countermeasure varies according to the measures collected and comparison treatment. Overall, reductions of fatalities, injuries, and accidents (weighted for vehicle and train flows) would be ideal effectiveness information. Numerous confounds and practical constraints limit field data collection and interpretation (see Evans, 1985; Hauer & Persaud, 1986). Cost per installation is expressed only in U.S. dollars.

Conversion to Canadian dollars will require adjustments for exchange rates, tariffs, inflation, and labour cost differentials.

Table 5.1 Countermeasure Type, Effectiveness, Cost, and References.

Countermeasure	**Effectiveness**	**Cost**	**Reference(s)**
Stop Signs at Passive Crossings	Unknown	$1.2 to $2 K (U.S.)	NTSB (1998a)
Intersection Lighting	52% Reduction in Nighttime Accidents over No Lighting	Unknown	Walker & Roberts (1975)
Flashing Lights	64% Reduction in Accidents over Crossbucks Alone; 84% Reduction in Injuries over Crossbucks; 83% Reduction in Deaths over Crossbucks.	$20 to $30 K (U.S.) in 1988	Schulte (1975) Morrissey (1980)
Lights & Gates (2) + Flashing Lights	88% Reduction in Accidents over Crossbucks Alone; 93% Reduction in Injuries over Crossbucks; 100% Reduction in Deaths over Crossbucks 44% Reduction in Accidents over Flashing Lights Alone	$150 K (U.S.)	NTSB (1998a) Schulte (1975) Morrissey (1980) Hauer & Persaud (1986)
Median Barriers	80% Reduction in Violations over 2-Gate System	$10 K (U.S.)	Carroll & Haines (2002a)
Long Arm Gates (3/4 of roadway covered)	67 to 84% Reduction in Violations over 2-Gate System	Unknown	Carroll & Haines (2002a)
4-Quadrant Gate Systems	82% Reduction in Violations over 2-Gate System	$125 K (U.S.) from Standard Gates $250 K (U.S.) from Passive Crossing	Carroll & Haines (2002a), Hellman & Carroll (2002)
4-Quadrant Gate System + Median Barriers	92% Reduction in Violations over 2-Gate System	$135 K (U.S.)	Carroll & Haines (2002a)
Crossing Closure	100% Reduction in Violations, Accidents, Injuries and Deaths	$15 K (U.S.)	Carroll & Haines (2002a) NTSB (1998a)
Photo/Video Enforcement	34 to 94% Reduction in Violations	$40 to $70 K per Install (U.S.)	Carroll & Haines (2002b)
In-Vehicle Crossing Safety Advisory Warning Systems (ICSAWS)	Unknown	$5 to $10 K (U.S.) per Crossing + $50 to $250 (U.S.) for a Receiver	NTSB (1998a)

Notes: Countermeasures are listed by approximate date of introduction. The effectiveness of a countermeasure is expressed as a function of the percentage reduction in accidents and other violations over some previous treatment. Cost is expressed in U.S. dollars for the most recent reference.

The use of stop signs at passive crossings heads a short list of potential safety improvements. The NTSB (1998a) recommended the use of stop signs at passive crossings unless a compelling engineering case could be made for not installing them. A number of considerations are provided that suggest if a stop sign were used, highway-railway collisions may be reduced. Train speed (i.e., high-speed passenger trains), traffic mix (e.g., buses, trucks, hazardous materials carriers), multiple tracks, skewed approach angles, and restricted sight lines are some of the considerations. Factors against stop sign use include maximum ADT of 400 in rural settings and 1500 in urban. Heavy vehicle use of the crossing or a roadway's steep ascent grade to the tracks are other factors against stop sign use. Should sight-line distances be increased from 10 seconds so that tractor trailers and buses can traverse crossings safely?

The NTSB (1998a) argues for the decision to integrate stop signs based on logic, their in-depth analysis of 60 passive crossing accidents, and historical debate. A definitive effectiveness study for stop signs needs to be done. Drivers tend not to respond to a stop sign at a highway-railway crossing in the same way they comply with road-road stop signs (i.e., drivers tend not to stop). Based on the FRA statistics (2001), stop signs have the highest accident, death, and nonfatal incident rates (per 100 crossings and 100K ADT) than any warning type. Canada should not adopt the NTSB's recommendation until the effectiveness of the stop sign can be established. To recommend the least effective warning device is, in our opinion, premature.

Effectiveness determination and adoption of alternative AWS's should be considered (e.g., see Lerner et al., 1990; NTSB, 1998a). Discrimination of active and passive crossings in advance is one avenue of research needed. Determination of the effectiveness of new AWS's in Canada is suggested. Will drivers be confused until they learn the new signs? Do they understand the signs that are currently used?

The range of options for active crossings presents many opportunities to improve the safety of Canadian highway-railway grade crossings. Complete closure and median barriers at existing gated crossings where violations are problematic are attractive for cost and effectiveness reasons. However, the politics of closure are nontrivial (Carroll & Haines, 2002a). An accounting of existing crossings, accident histories of each crossing, and a set of engineering and cost criteria for proposed solutions is needed. Ultimately, how much safety can be afforded by Transport Canada, the railway companies, and local governments is likely to determine the final outcome of this process.

6. QUANTITATIVE ANALYSES

6.1 Introduction and Methods

The purpose of the quantitative analyses was to characterize Canadian highway-railway grade crossing accidents over the past 19 years. A need exists to gain a better understanding of Canadian highway-railway grade crossing accident statistics (Coghlan, 2000; Fournier & Turgeon, 2000). A number of sources provide extensive cross tabulations of numerous variables (see, e.g., FRA, 2001). The approach taken here was to describe highway-railway grade crossing accidents over the span of collected data and to determine whether known accident problems also exist in Canada. In addition, long-term trends were analyzed to gain a predictive understanding of accident trends.

An extensive list of questions was developed, based in part on the taxonomy described previously, that could be used to query the frequency of certain cases in RODS (see Section 4). The literature review also guided the selection of both quantitative and qualitative (see Section 7) questions. The authors of this report and the analysts at the TSB worked together to determine the extent to which the various questions could be addressed. An acquired understanding of the data fields within RODS allowed the team to refine questions and ask a number of questions that were not conceived prior to working together.

The TSB's RODS was analyzed using quantitative and qualitative methods. There was a total of 7,819 incidents in RODS from January 1, 1983 to December 31, 2001 (19 years). Organization of the analyses moved from overall accidents to specific questions. Each accident was referenced by multiple fields such as date, location, type of crossing (e.g., passive, active, farm, private), fatalities, injuries, speed of the train, and so forth. All analyses excluded pedestrian accidents.

6.2 Accident Analyses

Figure 6.1 shows all accidents in RODS from 1983 to 2001. The frequency of accidents has clearly declined. The linear regression equation provides a reasonable fit of the data ($R^2 = 0.92$). Based on the regression equation, accidents are halved approximately every 17 years. Why accidents have declined year after year is not definitively known. Claims for the reduction should be rejected unless a definitive causal connection can be established (e.g., see Evans, 1991). Plausible reductions derive from a loss of track and thus a total reduction in the total number of crossings. For example, the total number of public and private crossings in the U.S. decreased by 9.3% from 1990 to 1996 (FRA, 1998). Grade crossing closures are the most effective way to reduce the potential for vehicle-train interactions and thus reduce collisions. Using the same regression equation, the frequency of future accidents can be predicted. In 2006, the estimated number of accidents would be 150.

A common analytic error is to draw conclusions about percentage increases and decreases of accidents over a limited time window of a year or two. Statements about a 5% decline over a previous year's reporting need to be interpreted with respect to the larger trend. It is a given that accidents are declining and have so for the entire span of recorded data. The most fallacious statements are those that attribute a yearly decline to specific interventions such as a new educational or media campaign. The attribution is most likely a political justification for money spent and the decline would have happened with or without the campaign. As an aside, educational and media campaigns are likely to raise awareness, but as a mechanism for changing behaviour at highway-railway grade crossings, the effectiveness of these campaigns is most likely negligible (e.g., see Evans, 1985, 1991; OECD, 1990). In combination with enforcement and other countermeasures, the effectiveness of educational campaigns should be assessed. The use of specific countermeasures and their relative effectiveness to reduce accidents are considered at length in Section 5.

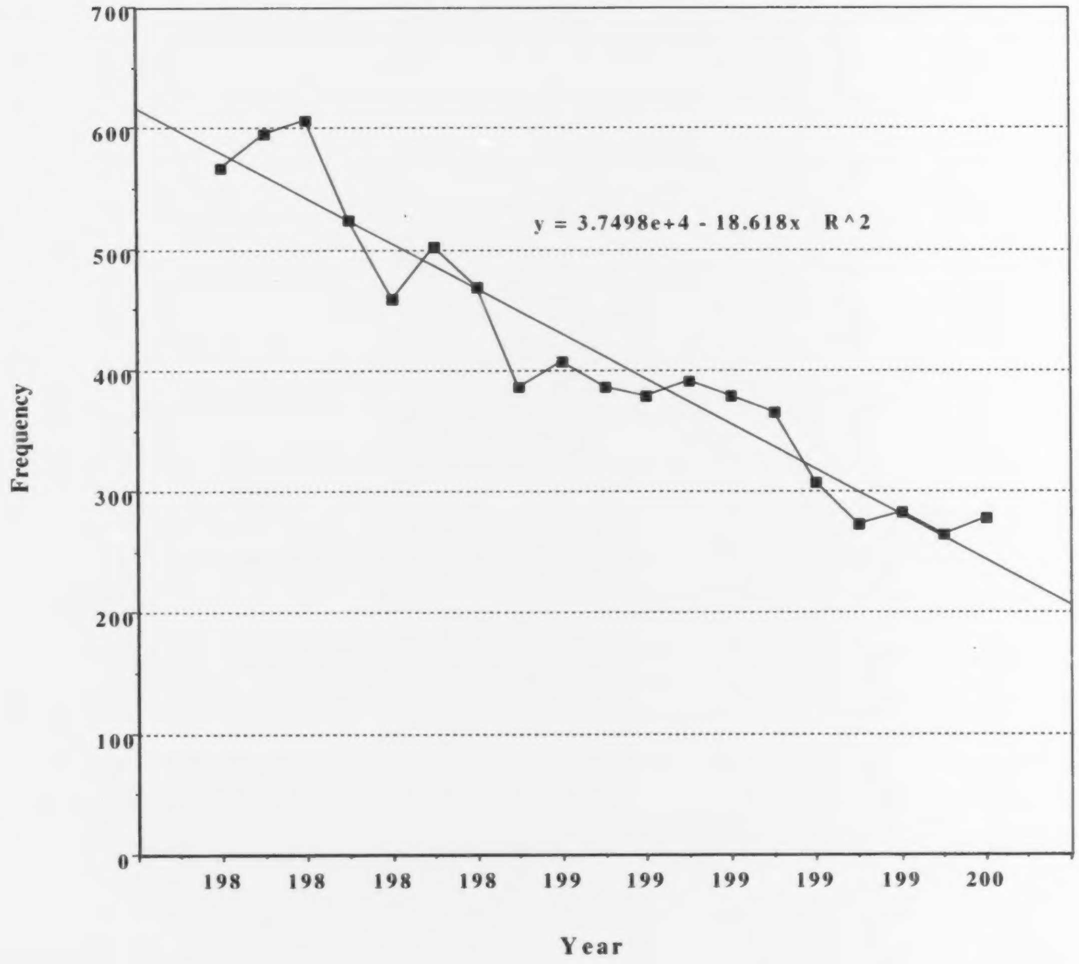

Figure 6.1 Total crossing accidents per year from 1983 to 2001 (N = 7,819).

Like total accidents, public automated and public passive warning accidents have declined by approximately half over the past 19 years (see Figure 6.2). The increase in private crossing accidents in 1993 reflects changes in the reporting requirements. Prior to 1993, only private and farm crossing accidents were reported if they involved casualties (minor/serious injuries or fatalities) or a derailment resulting in property damage worth $7,350 or more for main-track operations. As of 1993, all private and farm accidents must be reported.

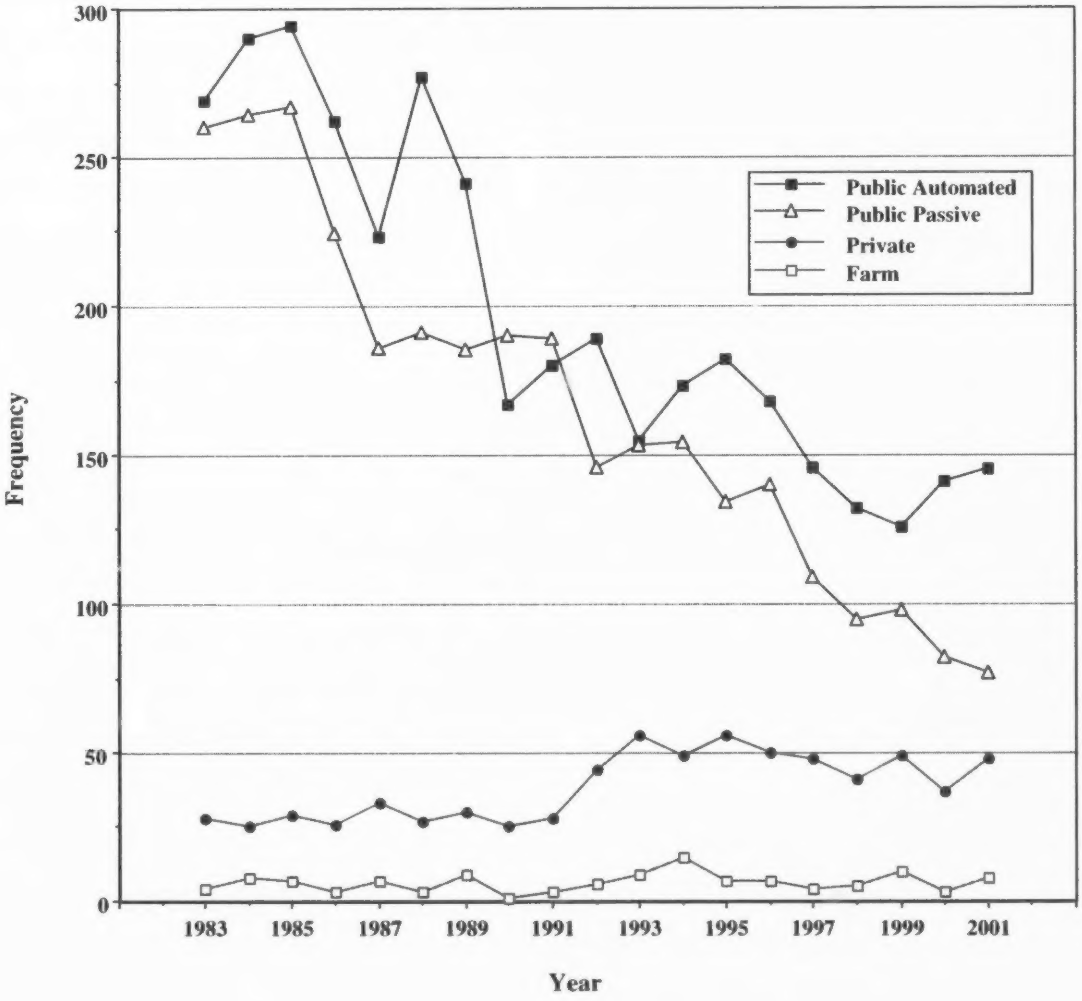

Figure 6.2 Accidents by crossing type per year from 1983 to 2001.

6.3 Fatalities, Injuries and Exposure Analyses

The reporting of accidents at highway-railway grade crossings, as with other events on the highway, is most meaningful in terms of a rate, as opposed to frequency of accident. There are more accidents at certain highway locations, such as urban intersections, primarily because there are more vehicles travelling there. Similarly, there will be more highway-railway crossing accidents in Ontario than in New Brunswick, primarily because there are more crossings, as well as more roadway and train traffic, in Ontario. Hence, it is appropriate to report accidents in terms of some index of exposure. This is typically expressed, in the highway safety literature, in terms of accidents per million vehicle kilometres, per 100,000 licensed drivers, or as a function of the number of roadway vehicles. In the case of roadway intersections the rate depends on the number of vehicles passing through the intersection per unit of time (e.g., per year or per month).

Similarly, for highway-railway crossings, a major determinant of the accident rate would be a function of the frequency with which both road vehicles and trains pass through the crossing. Hence, it is essential to know the volume of railway and roadway traffic. In addition, factors such as the length and speed of the train would be relevant. For example, a 12-car passenger train would occupy the crossing for much less time than a 100-car freight train because the latter is much longer and is typically slower. A freight train would occupy the crossing for a longer period of time, increasing the duration of exposure to road vehicles. This is especially a problem at night and under low visibility conditions such as snow or fog. Freight train incident data (FRA, 2001) indicate that trains longer than 100 cars have triple the accidents of other categories. However, because train length categories are increments of 5 cars (e.g., 41-45) or 10 cars (e.g., 81-90), the category of >100 may capture many more incidents because it is a more inclusive category. Passenger train incidents indicate that these trains are, in fact, much shorter than freight trains.

It may be more meaningful to discuss accidents in terms of number of collisions, rather than numbers of fatalities or injuries, since a single crash can involve several deaths or injuries to vehicle occupants. The point is that numbers of people involved can be a function of number of vehicle occupants, which is to some extent a matter of chance. One can ask whether a specific crossing is more dangerous than another when at the first crossing one crash killed 10 people (e.g., as in a bus accident), while at the second 10 crashes killed 10 people. It would seem to be the latter that is more dangerous. An additional consideration would be where the crossing is located and the types of road vehicles using that crossing. Those with a large number of heavy trucks may involve greater danger.

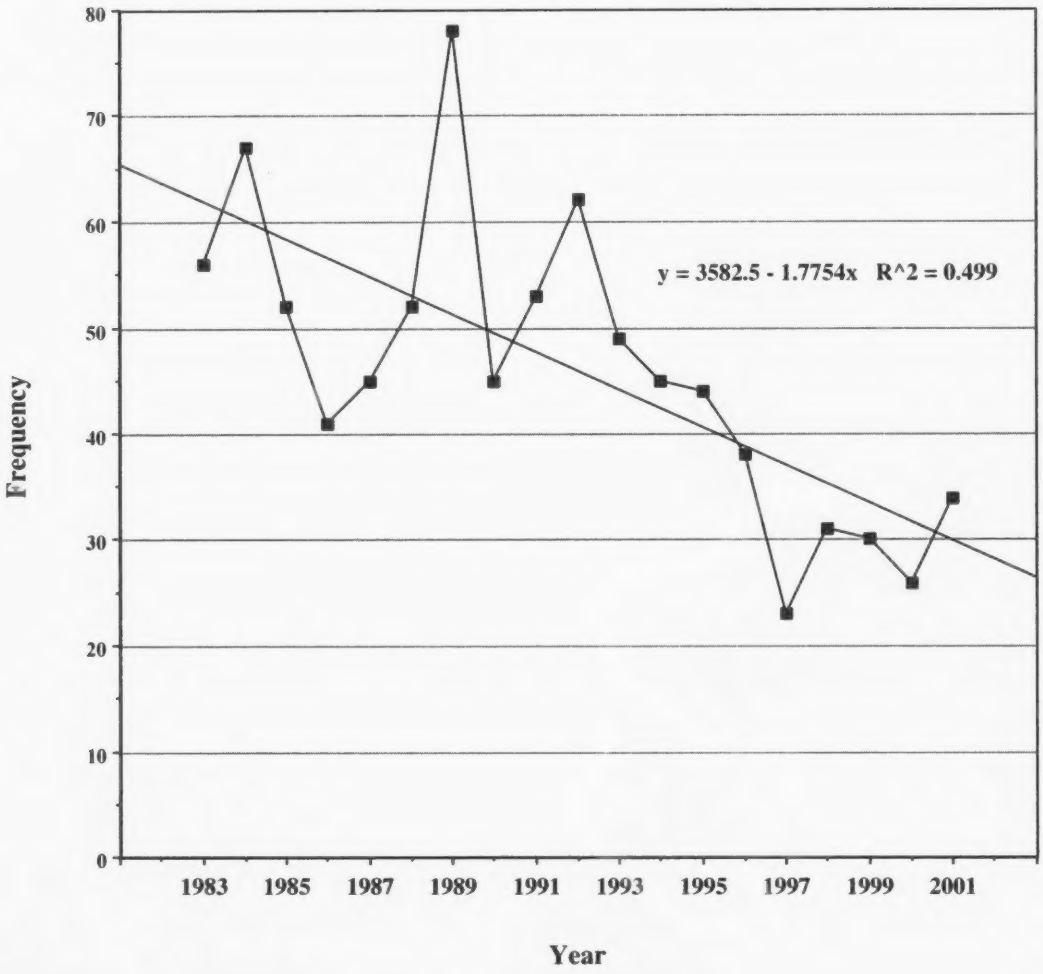

Figure 6.3 Total accident fatalities from 1983 to 2001.

Between 1983 and 2001, an average of 46 vehicle occupants were killed each year in Canada from highway-railway grade crossing accidents. Total occupant fatalities from 1983 to 2001 are shown in Figure 6.3. From 1983 to 1992, of the 551 vehicle occupant fatalities that occurred, 541 were classified as drivers and 10 as passengers. From 1993 to 2001, 246 were classified as drivers and 74 as passengers. The linear regression equation does not fit the data well ($R^2 = 0.50$). The years 1989 and 1992 reflect highs, whereas 1986 and 1997 reflect lows. Fatalities per year vary around the regression line, which attempts to fit the highs and lows.

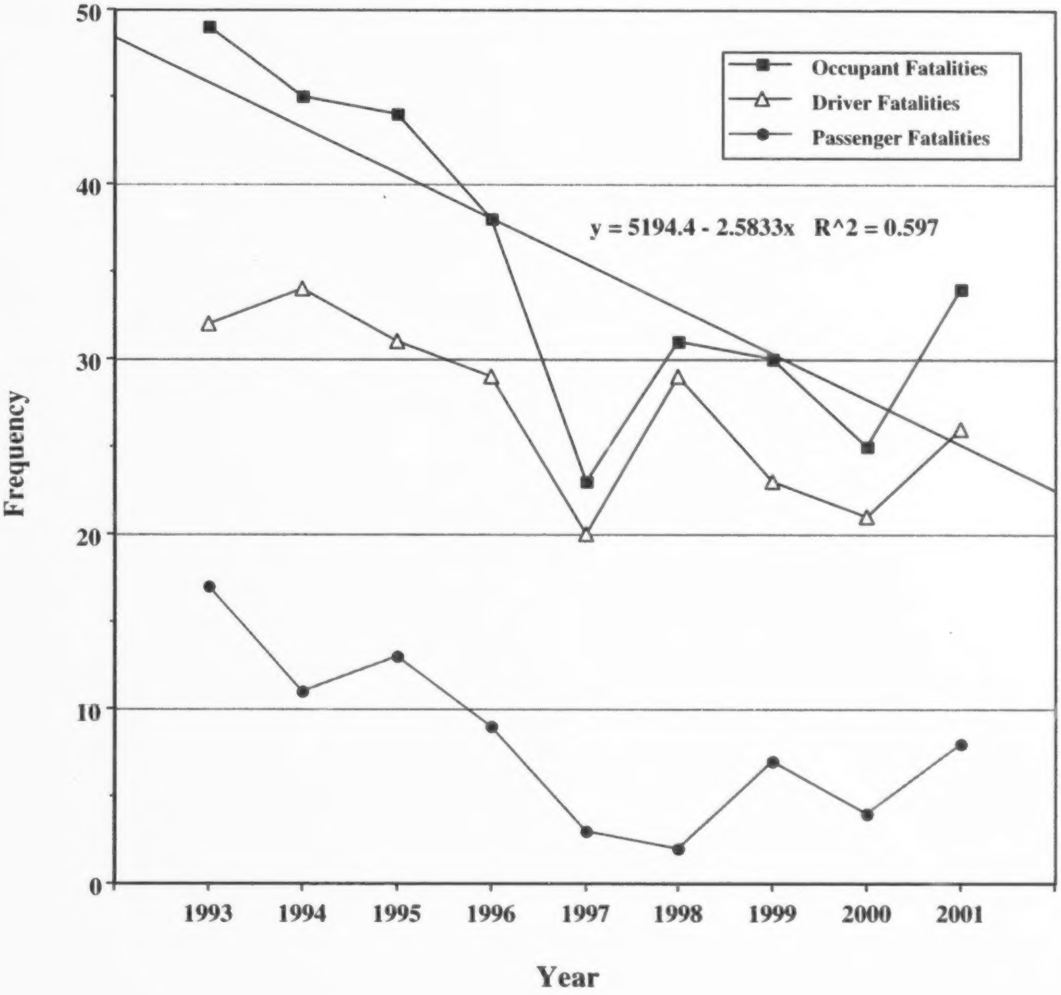

Figure 6.4 Vehicle occupant fatality types from 1993 to 2001 (N = 320).

The frequency of vehicle occupant fatalities per year has declined from 1993 to 2001 (see Figure 6.4). These numbers do not include pedestrian or trespasser fatalities. In general, fatality data are assumed to be somewhat more complete and accurate. Over this period a total of 320 fatalities occurred. The average number of drivers and passengers who died in highway-railway crossing crashes annually was 27 and 8, respectively. In 1993, 49 people died in crossing accidents compared to 34 in 2001. Classification of fatalities into driver and passenger categories was not consistently performed until 1993. Both fatality types have declined from 1993 to 2001. To predict the future number of fatalities per year, a linear regression equation was fit to all fatalities from 1983 to 2001 (N = 871). Based on this equation, an estimated 21 fatalities will occur in 2006. Overall fit ($R^2 = 0.50$) was relatively low. Fatality frequency oscillates or varies from year to year (e.g., compare 1997 and 2001). Greater yearly variance reduces fit.

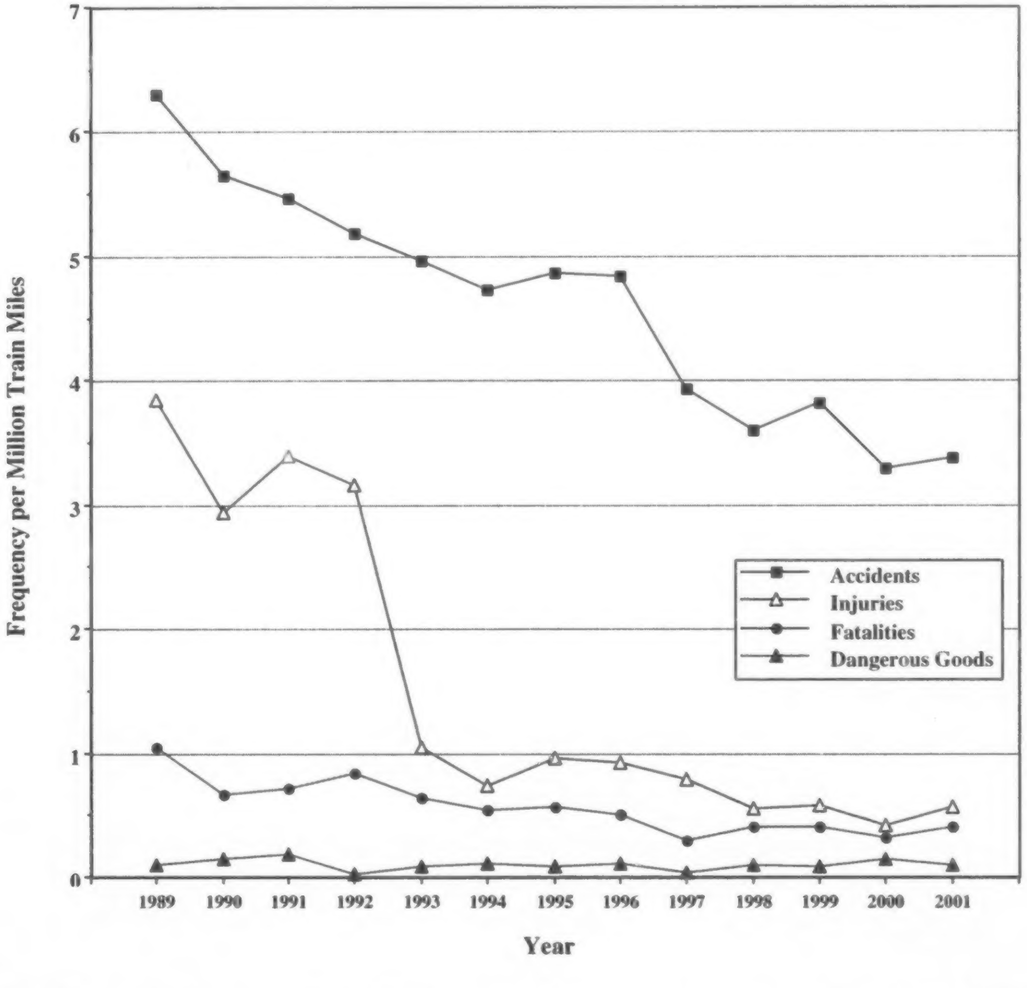

Figure 6.5 Accidents, injuries, fatalities, and dangerous goods per million train miles from 1989 to 2001.

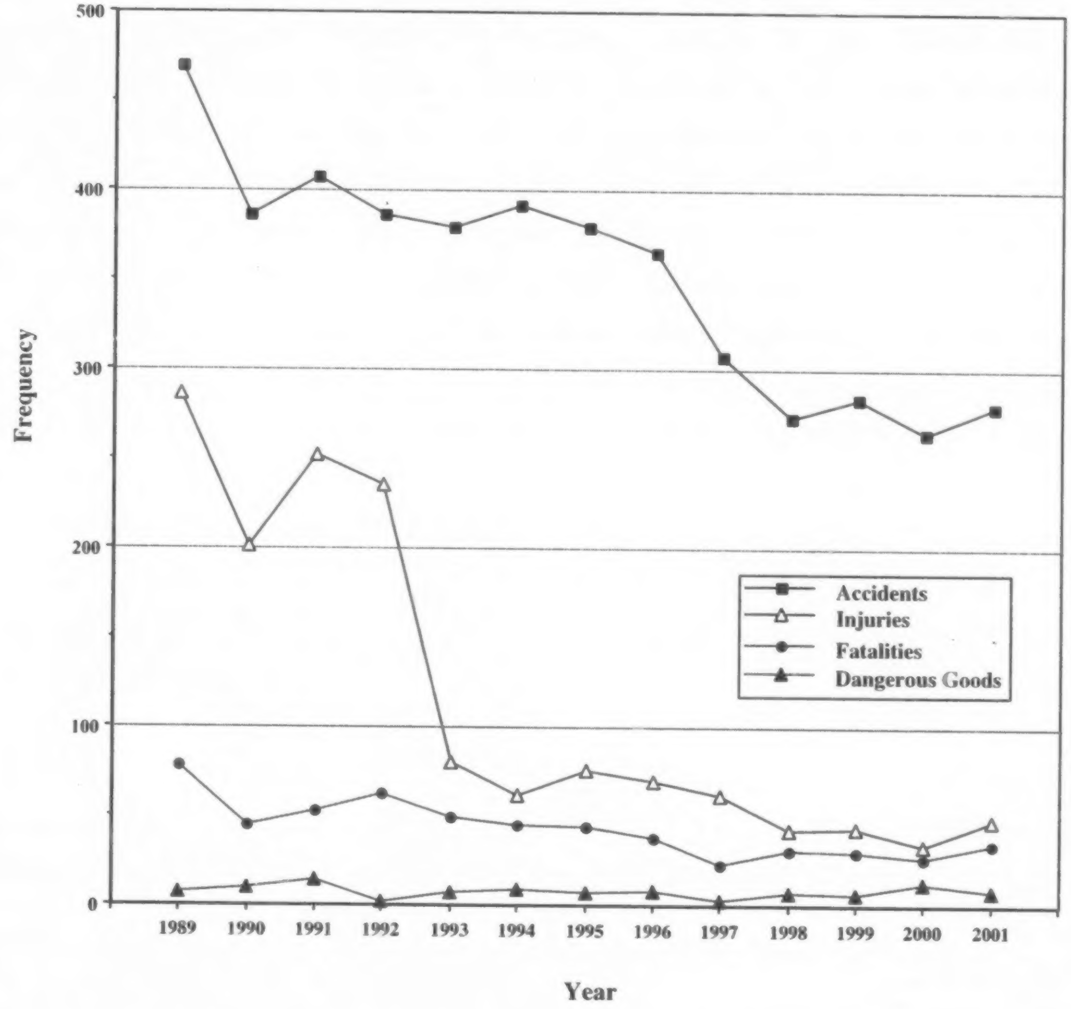

Figure 6.6 Frequency of accidents, injuries, and fatalities from 1989 to 2001.

Figures 6.5 and 6.6 illustrate accidents, injuries, fatalities, and dangerous goods expressed as frequency per million train miles (MTM) (6.5) and as a frequency (6.6). The dramatic drop in injuries between 1992 and 1993 is indicative of a change in classification criteria. The reporting criteria were changed by the TSB in 1993 from all injuries to just serious injuries. Accidents, injuries, and fatalities show declines from 1989 to 2001, while dangerous goods accidents remain constant.

Accident and injury lines indicate only slight differences as a result of the MTM adjustment. The two figures are strikingly similar. We expected that the four lines would have been "bent" more by the MTM adjustment in the denominator. MTM is based on the submission of mileage by the major railways and most likely introduces a constant error associated with monthly and yearly calculations. In 1997, the calculations of MTM were changed to include yard-switching miles. The exposure metric of MTM indicates train operation exposure, but not necessarily the interaction of vehicle and train volumes at different crossings. The use of exposure metrics such as MTM are not without limitations (Robertson, 1998).

Mileage as exposure does not indicate the kind of driving that is performed. Conceivably it is possible to have extremely high mileage and never cross highway-railway grade crossings. A measure of times exposed to crossings, which would be subjective, is needed. If exposure information were available for all the variables in this section, how would it affect the expression of data? Where travel is less for a particular variable, that variable would be accentuated and if travel is more, the variable would be less. Because younger and older drivers typically travel less than those actively working (Evans, 1988), if fatalities are expressed as a function of mileage driven (see Figure 6.7), the tails of the inverted "U" would be accentuated. The net effect of an "exposure" adjustment would be to steepen the inverted "U" of Figure 6.7. Further exposure adjustments to other variables would change their profile somewhat. The proportional relationships among variables will change and in some instances, the relative ordering of variables may change.

Will the *Direction 2006* objective of reducing highway-rail grade crossing collisions by half by the year 2006 be achieved? Depending on what is meant by a collision, one half of accidents since 1996 is 183, one half of serious injuries is 27, and one half of fatalities is 19. Using linear regression, an estimated 150 accidents, 6 injuries, and 21 fatalities should occur in 2006. These estimates can be inaccurate because injuries and fatalities from year to year are highly variable. *Direction 2006* will most likely achieve its accident goal based on current data.

From 1993 to 2001, a total of 155 fatalities occurred where the gender and age of the occupant were known. Figure 6.7 shows the number of fatalities for each age group and gender. In this small sample, males were involved in 77.4% of crossing fatalities, whereas females were in only 22.8%. In all age groups, the frequency of male fatalities is higher than that of female fatalities. The age group of 26 to 64 accounted for 66.5% of all fatalities. This age proportionally drives the most and thus has the greatest exposure (Evans, 1991). To determine why males are killed more frequently requires exposure data on both men and women. Do men use railway crossings more frequently, less safely or both? Cautious interpretation of this data is warranted. A similar pattern of male involvement was reported by the FRA statistics (FRA, 2001). However, fatalities by age group in the FRA incident data (2001) for the year 2000 are categorized by under 16 (N = 61), 16 to 21 (297), and over 21 (425). This classification scheme indicates a potential problem for younger drivers, but does not provide a means to understand the accidents of drivers over 21.

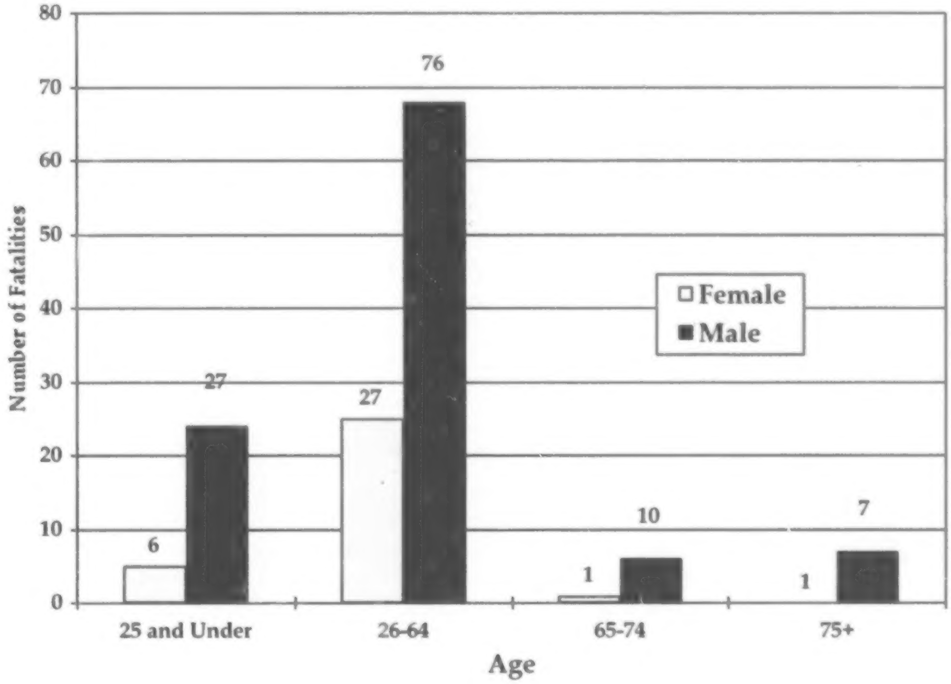

Figure 6.7 Fatalities by age and gender from 1993 to 2001 (N = 155).

Figure 6.8 illustrates the vehicles that were involved in fatalities over the past 19 years. Automobiles were involved in 53% of crossing fatalities from 1983 to 2001 (N = 871). Light trucks, tractor trailers, heavy trucks, and vans comprised 40% of fatalities. Light trucks, which were involved in 27% of fatalities, typically operate in rural and industrial urban areas where more tracks are present. Dangerous goods trucks were involved in 2 fatalities (0.23%) from 1983 to 2001 (e.g., see TSB 1993, October). Similar vehicle involvement percentages occurred in the U.S. (FRA, 2001). The other category includes motorcycles, bicycles, emergency vehicles, snowmobiles, all-terrain vehicles, graders, farm tractors, farm equipment, and wheelchairs.

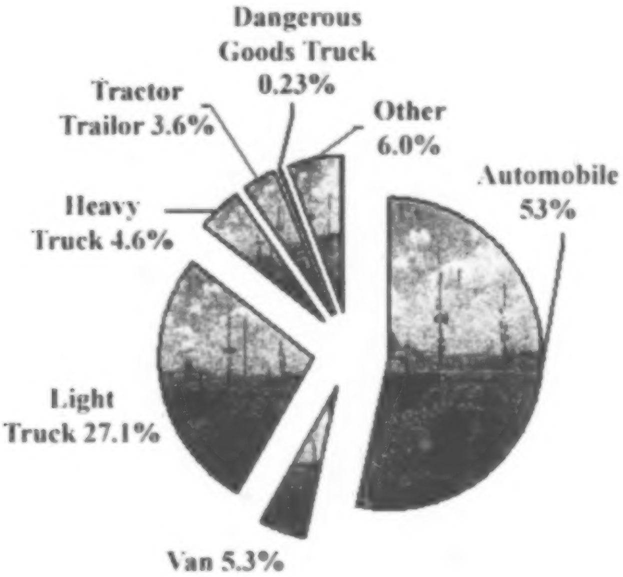

Figure 6.8 Vehicle occupant fatalities by vehicle type from 1983 to 2001 (N = 871).

Trucks in the U.S. are over-represented in vehicle-train collisions (Loumiet & Jungbauer, 1995; Mortimer, 1988). One possible reason is that they are slow moving and cannot accelerate across the tracks within the sight-distance design guidelines. Bus (Kendall & Morrissette, 1995, May) and tractor trailer (Kendall & Morrissette, 1995, July) acceleration over tracks that varied in number and load indicated that the 10-second railway sight-line rule may be inadequate under certain conditions. Specific conclusions about the capability of buses and tractor trailers to adequately accelerate from a dead stop can be found on page 5-1 of both reports.

The capability of fully loaded trucks to come to a complete stop in advance of a crossing when roadway conditions are snowy, icy or wet is another concern (e.g., see TSB, 1991b, January). Large trucks commonly derail trains when collisions occur, leading to extensive, costly damage.

6.4 Crossing Type, Intersection Geometry, Traffic, and Train Flow

Configurations of grade crossing and train and traffic flow affect accidents. The presence of different types of active and passive signs and signals at accidents have been recorded since 1993 (N = 2,710). Active crossing types (i.e., those with gates, lights and bells; lights and bells only; or an active unknown) comprise approximately 56% of accidents (see Figure 6.9). Of these, flashing lights were at 73.6% of accidents, while FLBs and gates were at 27.2%.

Independent of crossing type, 75.5% of accidents happened with an AWS present, another 14% with stop signs, and 10.5% other. Signs and signals (i.e., AWS, stop, unknown passive, and other passive) totalled approximately 44% of accidents. Private crossings with stop signs had the highest number of accidents of passive crossings (N = 108). Stop signs are most likely used more frequently than other signs at private crossings. Accidents, deaths, and non-fatal accidents by warning type indicate that stop signs had the highest rates per 100 crossings, followed by flashing lights, gates, and crossbucks (FRA, 2001).

The use of an AWS prior to an active crossing may not make this classification of passive and active perfectly separable. For example, 809 accidents had an AWS at automated crossings and 309 were at public passive crossings. Ideally, an automated crossing is classified as active with an AWS. Automated or active crossings had 51.3% missing cases and passive crossings had 45.2% missing cases. These higher numbers indicate the number of cases not classified prior to 1993 as well as the number of passive and active unknown since 1993.

In the U.S., a disproportionate number of accidents happen at active crossings (Carroll & Haines, 2002a; Mortimer, 1988). Approximately 78% of crossings in the U.S. are passive and 22% are active. Forty-five percent of accidents occurred at passive crossings (i.e., stop signs and crossbucks) and 48.2% of highway-railway grade crossing incidents happened at active crossings.

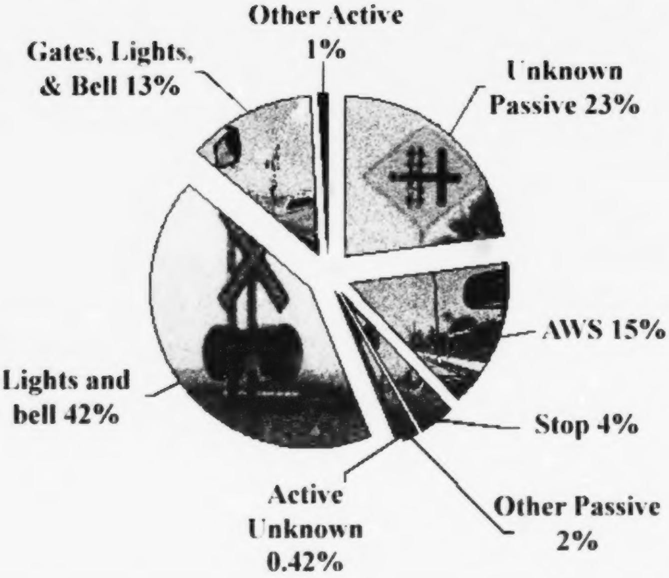

Figure 6.9 Percent of accidents for each type of sign and signal from 1992 to 2001

Highway-railway grade crossing angles may contribute to train visibility difficulties (Mortimer, 1988). Within RODS, crossing accidents were the most frequent for crossing angles of 80° or less (or more than 100°). The crossing accidents were cross-referenced with Transport Canada's Integrated Rail Information System (IRIS) database to obtain angles for the crossings (see Figure 6.10). The angles provided by both RODS and IRIS are usually the crossing angles (i.e., smallest angle) and not necessarily the accident angle. For example, fewer than 100 of the accident crossings in RODS have an angle greater than 100°.

The IRIS information indicates that more than half of accidents happened where the intersection angle was 80° or less. Where tracks and roadway are perpendicular, the angle is 90°. An 80° intersection could also be 100° (opposite angle). Although this information cannot really be interpreted in context, more accidents happen at crossings with angles below 80° and greater than 100°.

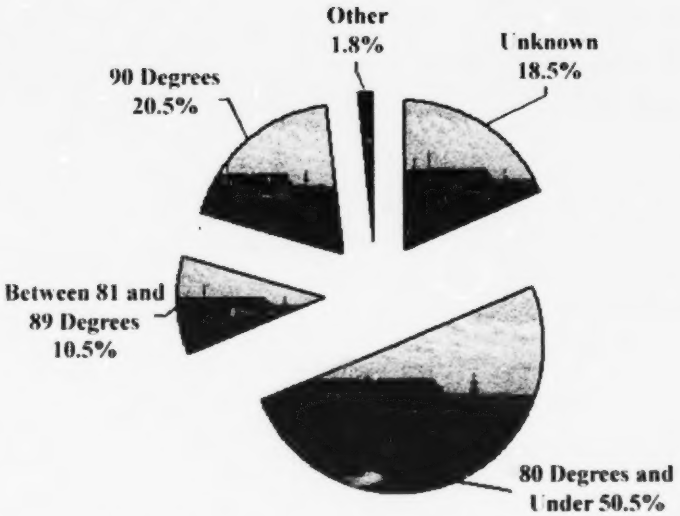

Figure 6.10 Crossing accidents by angle from 1983 to 2001 (N = 7,819).

Ideally, the intersection angle should indicate the approach direction of the highway user and train travel direction. Therefore, the angle information provided by both IRIS and RODS is only marginally useful. Collection of accurate angles and the direction of travel for both the train and vehicle would improve the resolution of the answer to this line of enquiry. Ultimately, if a train is approaching a driver from behind, it would be more difficult to turn and see it than if it was approaching from an angle that placed it closer to the forward travel path (Åberg, 1988; Mortimer, 1988; NTSB, 1998a).

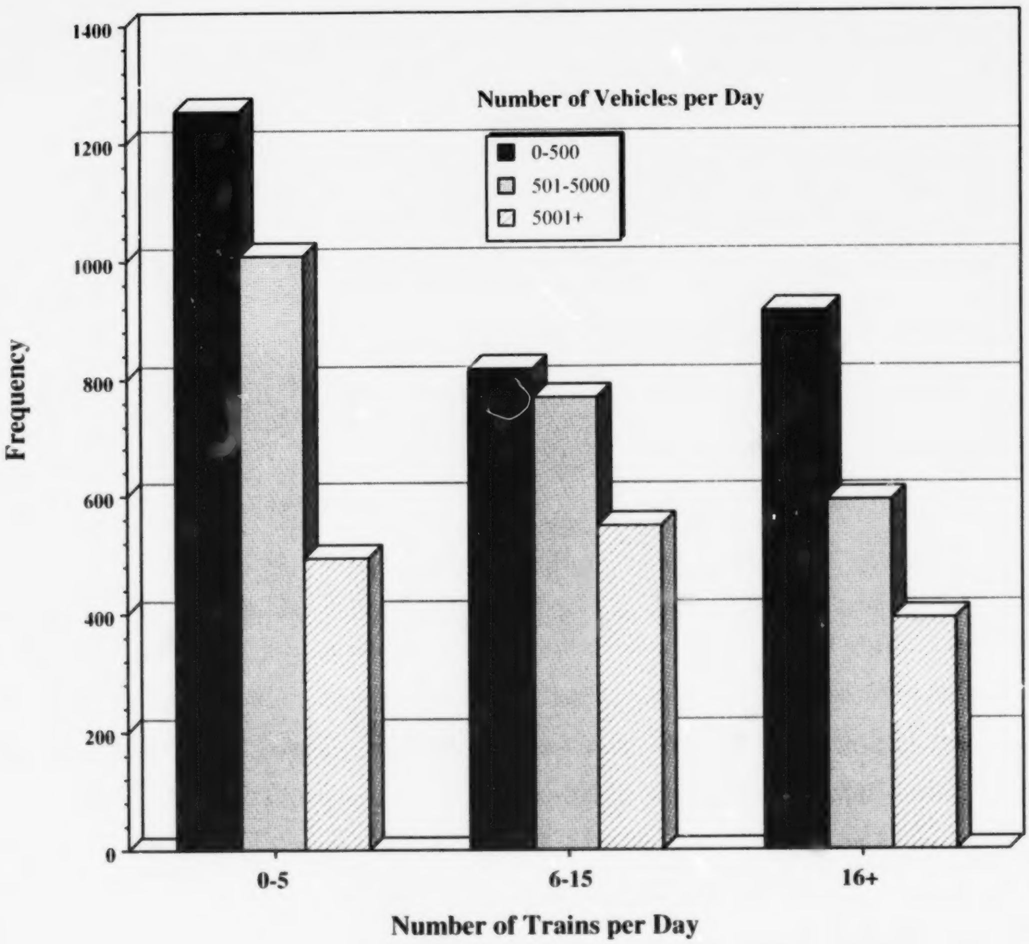

Figure 6.11 Accident frequency based on vehicle and train flow per day from 1983 to 2001 (N = 6,795).

From 1983 to 2001, lower vehicle flows (0 to 500 per day) seem to be related to higher frequencies of crossing accidents (see Figure 6.11). From 1993 to 2001, 1,262 of 3,264 accidents happened at urban intersections and 1,085 occurred at rural intersections. Where low levels of traffic flow exist, such as at rural intersections, may be where more accidents happen. When traffic flow exceeded 5,000 vehicles per day, accident frequencies were somewhat similar across categories of train flow. Given warrants based on vehicle and train flow discussed in Section 2, crossings with high vehicle flows, high-speed passenger trains, and a history of accidents are more likely to be protected by gates, bells, and lights. Forcing functions such as gates will reduce the probability of crossing accidents. Higher flows in urban areas are more likely to be protected by gates, bells, and lights, but not all urban crossings have this more costly crossing defence. Carroll and Haines (2002a) observed that violations of gated systems were more likely with less congestion at the crossing. Higher traffic flows and congestion may limit the opportunity to drive around other vehicles and gates.

6.5 Time of Day and Year

About 40% of all accidents occur between 9:31 a.m. and 3:30 p.m. Figure 6.12 shows the frequency of all eligible accidents by time of day from 1983 to 2001. Approximately 29% occurred during peak commuting times in the morning and evening. The frequency of daytime accidents is similar to that found by other rail investigators and researchers (FRA, 2001; Hellman & Carroll, 2002; NTSB, 1998a; Wigglesworth, 1979). Clearly, the preponderance of rail accidents happen during the day.

The relative number of fatalities is less during the day (9:31 a.m. to 3:30 p.m.) and more in the morning hours (12:01 a.m. to 9:30 a.m.). Figure 6.13, fatality frequency by time of day, is quite similar to 6.12. Fatalities are highest from 9:31 a.m. to 3:30 p.m. The FRA data (2001) indicate that weekdays (Monday to Friday) have the highest total incidents. On Saturday and Sunday, the total number of accidents declines sharply (also see Wigglesworth, 1979).

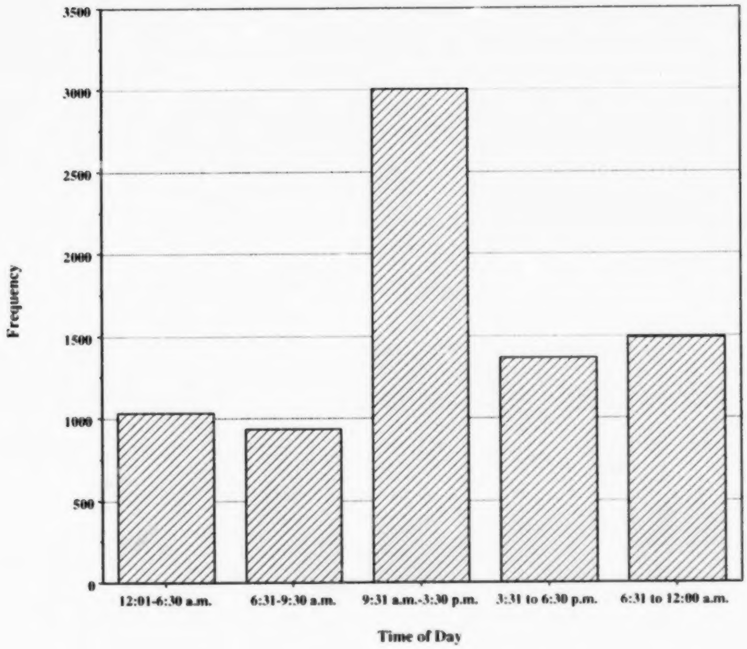

Figure 6.12 Accident frequency by time of day (N = 7,819).

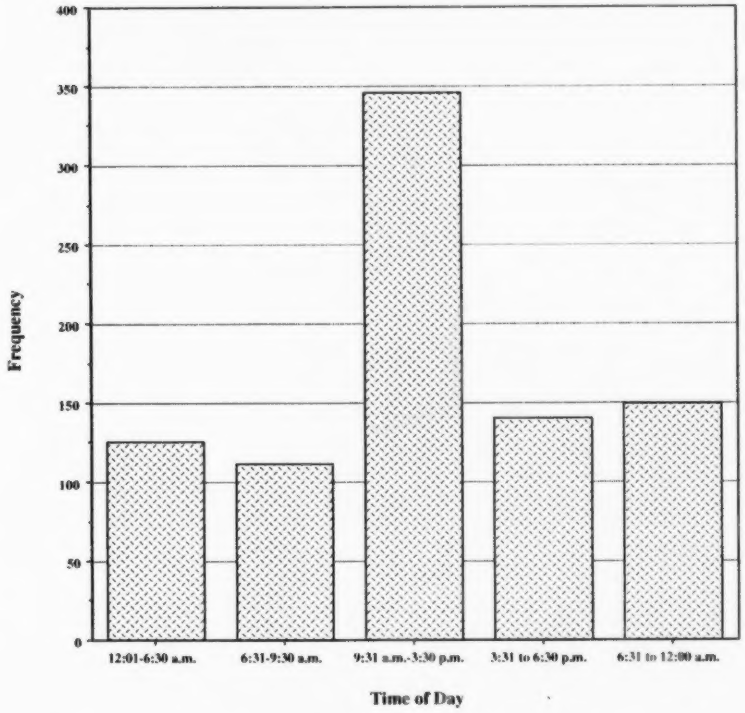

Figure 6.13 Fatality frequency by time of day (N = 871).

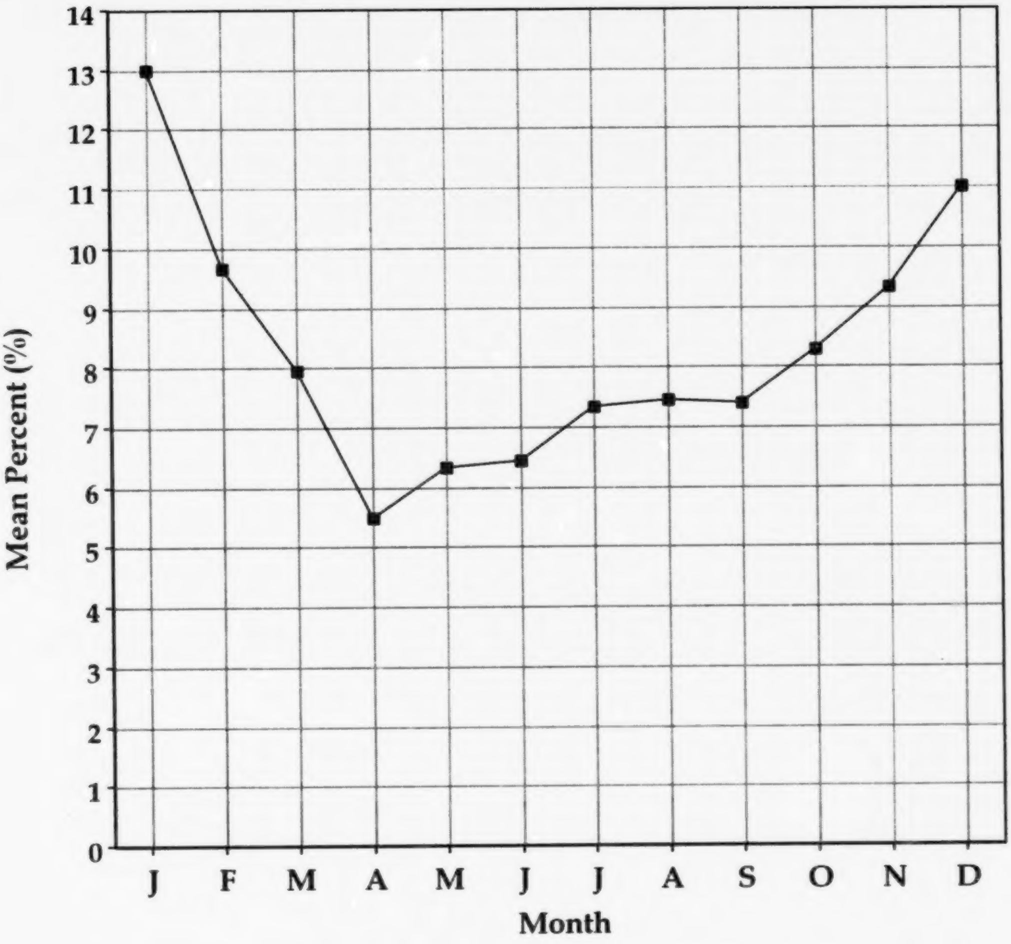

Figure 6.14 Mean percent of accidents by month from 1983 to 2000 (N = 7,541).

Weather patterns within Canada vary from year to year, with a trend toward warmer winters. To reduce the influence of weather from any single year on the frequency of accidents, data from 1983 to 2000 were averaged and the percentage of contribution of each month to the total was calculated (see Figure 6.14). January and December have the highest percent of accidents per year and April has the lowest. The FRA's tabulation of crossing accidents/incidents for 2000 shows the same monthly pattern, with peaks in December and January and a low in April (FRA, 2001).

A higher frequency of accidents in winter months (i.e., November to February) could be attributed to several factors. From 1993 to 2001, there were 443 accidents where the road conditions were considered icy or snow-covered (also see Table 6.2). Many drivers do not adjust the speed of their vehicles appropriately to these unsafe environmental conditions. As they reach a crossing, drivers may attempt to stop but they slide into the crossing and are struck by or slide into the train. A number of accident narratives illustrate this description (also see Section 7). A second factor that may increase accident risk during the winter is reduced visibility due to fewer daylight hours, blowing snow, ice fog, and so forth. Thus, trains travelling through crossings are missed for a variety of reasons, including conspicuity. Slow-moving trains under these conditions may pose especially difficult conspicuity issues (Mortimer, 1988; NTSB, 1998a).

For example, the TSB extensively investigated a collision between a tractor trailor and a passenger train. Four passengers were killed and 10 required medical attention (TSB, 1992, February). When the collision occurred, snow and ice covered the roadway. The tractor trailer did not stop before it collided with the passenger club car.

6.6 Unsafe Acts and Conditions

The accidents listed in Table 6.1 have been categorized using the TSB's unsafe acts criteria, which have been in use consistently since 1999. Unsafe acts were described by Reason (1990) and incorporated into the TSB's investigation process. An unsafe act is defined as "more than just an error or a violation—it is an error or a violation committed in the presence of a potential hazard: some mass, energy or toxicity that, if not properly controlled, could cause injury or damage" (Reason, 1990, pg. 206). The data are aggregated so that individual culpability is not identifiable. The most prominent category is "failed to stop", as 70.6% of all incidents were categorized. Of these, 162 cases could not be classified into intentional or unintentional. Classification of intent is based on Reason's (1990) taxonomy of human error types. An intentional act requires an explicit goal. In 107 cases, it is apparent that the intent of the driver was to travel through a crossing perhaps to beat the train so that he/she did not have to wait for it to pass. Driving around the gates (3.9%) and through the gates (1.6%) are usually cases of willful violations of the crossing protection. In 161 cases, the driver may not have stopped in time due to not seeing the train, not seeing the advance warnings or the train, and so forth. Where there is ice, snow or gravel, or the driver is approaching a crossing at a high rate of speed, skidding onto the tracks becomes possible (6.9% of accidents). Vehicles being stuck on the tracks (4.3%) and stalled on tracks (4.1%) identify a tense situation.

Table 6.1 Unsafe acts and intent from 1999 to 2001.

Crossing Type	**Unknown**	**Intentional**	**Unintentional**	**Total**	**Percent**
Failed to Stop	162	107	161	430	70.6
Skidded onto Track	7	6	29	42	6.9
Stopped too Close	4	9	13	26	4.3
Stuck on Track	7	1	18	26	4.3
Stalled on Track	1	6	18	25	4.1
Drove Around Gates	1	21	2	24	3.9
Stopped then Proceeded	4	.	7	11	1.8
Drove Through Gates	1	8	1	10	1.6
Vehicle Pushed onto Track	1	1	3	5	0.8
Drove into Second Train	.	.	1	1	0.2
Total	188	159	253	600	100.00

The FRA (2001) incident data for motorist actions are classified by warning type (i.e., gates, FLBs, crossbucks, etc.). "Drove around the gates" was the most common action for gates while "did not stop" was the most frequent action at FLBs (452), stop signs (186), and crossbucks (753).

Table 6.2 catalogs the incidence of unsafe weather conditions from 1998 to 2001. Snow, ice and fog rank first, second and third. Sixty-eight percent of highway-railway incidents in the U.S. occurred in clear weather (FRA, 2001). A further 21.5% occurred while it was cloudy, 5.5% when rainy, 3.0% when snow was present, and 1.7% when foggy.

Table 6.2 Unsafe weather and lighting conditions from 1998 to 2001.

Condition	**1998**	**1999**	**2000**	**2001**	**Total**
Snow Covered	2	5	4	3	14
Icy	4	2	.	.	6
Fog	1	2	1	1	5
Rain	.	2	2	.	4
Wet	2	.	.	1	3
Sun Glare	1	1	.	.	2
Night	.	1	1	.	2
Wind	.	.	1	.	1
Dusk	.	1	.	.	1
Total	10	14	9	4	38

Table 6.3 Unsafe internal conditions from 1998 to 2001.

Condition	1998	1999	2000	2001	Total
Attitudes	115	28	22	24	189
Attention/Vigilance	4	60	30	13	107
Information Processing	13	21	14	2	50
Mental/Emotional State	6	9	4	3	22
Alcohol	3	9	3	1	16
Planning	1	6	1	1	9
Handicap	.	2	.	.	2
Vision Limitations	.	2	.	.	2
Experience/Recency	.	1	.	.	1
Total	142	138	74	44	398

Attitudes, attention/vigilance, and information processing rank highest among unsafe internal conditions from 1998 to 2001 (Table 6.3).

6.7 Additional Questions

A number of questions could not be completely answered using RODS. Among these were, "What is the frequency of second train accidents or accidents that occur at multiple track crossings?" The prototypical accident of this type occurs when a driver proceeds across a crossing after the first train has passed and a second train, which is not expected, strikes the vehicle. A partial answer was derived. Based on crossing RODS and IRIS data (N = 7,776, through Nov. 7, 2001), the frequency of accidents at one and more tracks could be determined. From 1983 to 2001, 4,625 accidents occurred when one track was present, 1,273 occurred when there were two tracks, and 460 occurred when three or more tracks existed (up to nine tracks). In 1,418 cases, the number of tracks was unknown. It is known that crossings with multiple tracks in urban areas have the highest accident risk (Coleman & Stewart, 1976).

One clear case of a second train striking a driver was identified using the TSB's unsafe acts categorization (see Table 6.1). However, prior to 1999 the frequency of second train accidents is unknown. Given that several new technologies are targeted at the second train accident scenario, it would be useful to know to what extent it is a problem in Canada.

TSB rail accident report number R94D0191 describes a second train collision (TSB, 1994, November). A loaded tractor trailer was struck by a passenger train at about 8:12 p.m. on November 4, 1994, in Quebec. The tractor-trailer driver had stopped at the crossing with lights, bell, and gates for a freight train to pass. Once it had and the gates had been raised, he proceeded. Seconds later the active warning system reactivated with the approach of the passenger train. After observing the passenger train approaching, the truck driver jumped from his truck and got out of the way. The train struck the truck and derailed the leading locomotive. A fuel tank on the locomotive was punctured and the leak fed a fire on the locomotive and first car. It was extinguished by the locomotive engineers and the local fire department. Two passengers and two locomotive engineers had minor injuries. In certain circumstances, when approaching a crossing, the driver can be in a situation where he can neither stop nor accelerate over and clear of the track (TSB, 1994, November, pg. 10).

Several other questions also could not be completely addressed. Crossings that are in proximity to other intersections are more likely to have accident occurrences (NTSB, 1998a; Wigglesworth, 1979). From 1993 to 2001, RODS returned the frequency of accidents at traffic lights (6), flashing lights and traffic light (8), and FLBs, gates, and traffic light (7). The true extent of this accident type may need police and RCMP collision reports. More importantly, this type of accident configuration was confirmed in the narrative analysis. Figure 6.15 illustrates the potential difficulties faced by drivers at intersections near highway-railway crossings.

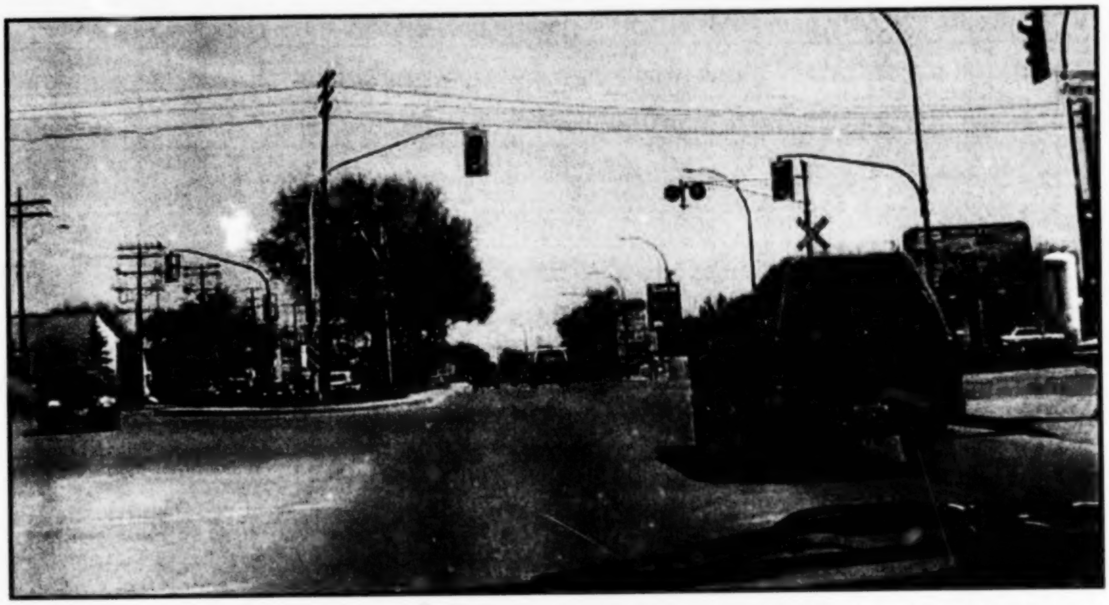

Figure 6.15 An intersection and a grade crossing in close proximity in urban Winnipeg. The visual demand of other vehicles, sign clutter, and signals make decisions to stop more difficult. The synchrony of the intersection lights (green) and crossing lights (flashing red) is not ideal. Interconnection of traffic lights and highway-railway grade crossing signals is suggested (Bremer & Ward, 1997).

Similarly, where a road travels parallel to a train track and then crosses it perpendicularly is also a known problem (Åberg, 1988; Wigglesworth, 1979). RODS, in combination with other data sources such as police and hospital reports, or the addition of more in-depth investigations may fill in these gaps in data and understanding. The qualitative analyses (Section 7) add somewhat to this accident configuration. Figure 6.16 illustrates the potential difficulties encountered at perpendicular crossings.

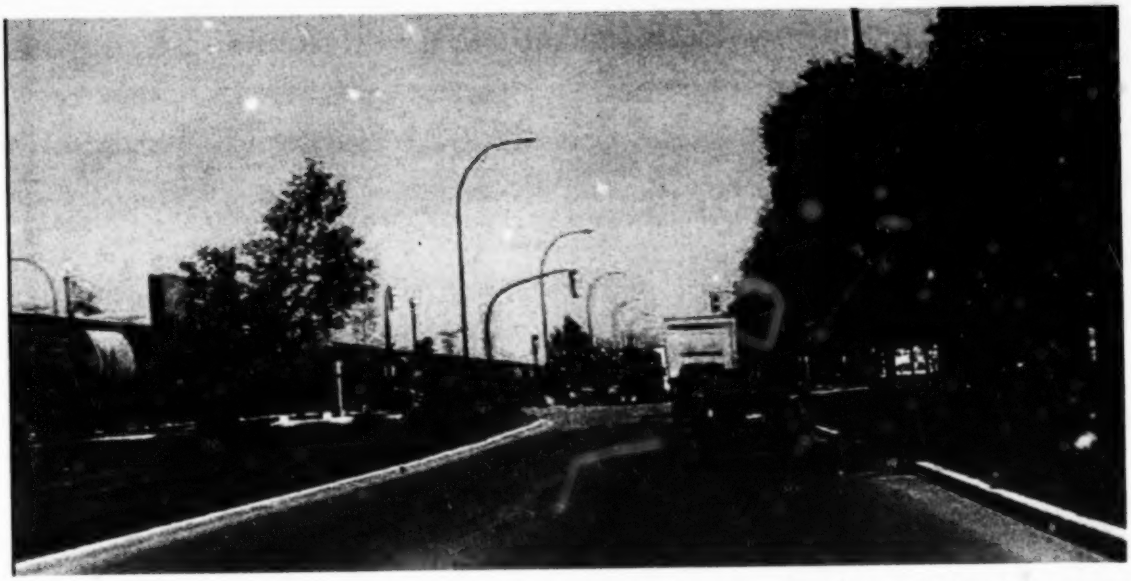

Figure 6.16 An intersection prior to a perpendicular crossing in an industrial area of Winnipeg. The AWS is partially obscured by tree branches and shadows on the right. The intersection ahead is controlled by lights (yellow). Notice the logging truck attempting to turn right in the intersection. The driver of the truck is blocking traffic in the intersection until the train has passed. The activity in the intersection demands the attention of the driver. The highway-railway grade crossing may receive less attention as a result.

6.8 Quantitative Results Summary

The purpose of the quantitative analyses was to characterize Canadian highway-railway grade crossing accidents over the past 19 years. Prior to this report, statistics were tabulated yearly with some trend data. This analysis provides long-term trends and a range of variable descriptions previously unanalyzed.

- The overall frequency of highway-railway grade crossing accidents, injuries, and fatalities has declined from 1983 to 2001.
- From 1993 to 2001, vehicle occupant fatalities (i.e., drivers and passengers) show considerable variability in number from year to year compared with accidents in general.

- Public active crossings had more accidents overall (56%) than public passive crossings (44%). The finding that more than half of grade crossing accidents occur at active crossings, despite the existence of far fewer active crossings overall, is consistent with findings from other countries such as the U.S.

- The majority of accidents (50.5%) happened at crossings with an angle of less than 80°. However, this requires cautious interpretation, as IRIS tends to report the smallest crossing angle. RODS also tends to report the smallest angle rather than the accident angle.

- Automobiles were involved in the most fatal accidents since 1983 (53%), followed by light trucks (27%), vans (5.3%), heavy trucks (4.6%), and tractor trailers (3.6%).

- Averaged from 1983 to 2000, January and December have the highest percentage of accidents per year. Winter weather produces visibility restrictions such as fog, snow or overcast conditions, and drivers need longer stopping distances on icy or snowy roads.

- Most accidents occurred during daytime hours (38%, 9:30 a.m. to 3:30 p.m.), which is consistent with previous research. Exposure data are often not considered when discussing this higher number of daytime accidents at grade crossings. For example, most drivers are usually on the road during the daytime. A further 29% of accidents happened during the morning (6:30 a.m. to 9:30 a.m.) and evening rush hours (3:30 p.m. to 6:30 p.m.).

7. QUALITATIVE ANALYSIS

7.1 Introduction and Methods

The purpose of conducting a qualitative analysis independent of the quantitative analysis was to determine whether accident narratives could further elucidate driver behaviour at highway-railway grade crossings. The narratives provide additional descriptive information that may enhance the understanding of the quantitative findings within RODS. Because the mandate of the TSB does not focus on highway safety *per se*, additional information about highway-railway accidents can provide convergent support for our research questions. The patterns of contributing factors observed in the quantitative data capture some but not all contributing factors. Many of the narratives in RODS provide excellent descriptions of known driver behaviour contributors to railway grade crossing accidents. From these narratives, several error categories were derived based on driver behaviour contributors and on physical conditions that interact with driver characteristics to potentially cause accidents. A qualitative analysis of narratives has yielded interesting results when applied to the use of in-vehicle devices such as cell phones (Goodman, et al., 1999) and driver distraction (Stutts, et al., 2001; Wierwille & Tijerina, 1996). To our knowledge, the application of this method to highway-railway crossing accidents has not been done previously. The method uses keywords to query RODS narratives. Cases are reviewed to determine whether common factors are present.

The use of keywords to identify cases of a specific accident contributor may not necessarily guarantee that all cases of a specific type are returned from the database. Thus, conclusions regarding the rank ordering of types of narratives should be cautiously interpreted. The value of providing sample narratives lies in the provision of prototypical accident descriptions that match commonly used causal descriptors. Thus, a rich description is given that is in accord with previous research and expectation.

The crossing accidents within RODS span 19 years, although the TSB itself was not created until 1990. Therefore, data prior to 1990 are considerably different from data collected after 1990. For example, most crossing accident narratives consist of only single phrase descriptions about the incident such as "failed to stop" or "drove around gates". Of the 3,722 narratives from 1983 through 1989, "failed to stop" is the most common identifier that appears (N = 409). Another common driver behaviour identified was "drove around gates" (N = 34). The "not applicable" (N/A) category (N = 1,307) also occurs frequently during this time period. Data in RODS reflect the difference in data collection prior to the TSB's inception.

After 1990, narratives increase in length and quality, expanding from a single phrase to a few sentences. There also appears to be an increased attempt to describe incidents in terms of driver behaviour. The terms "preoccupied" (N = 38), "distracted/distraction" (N = 12) and "inattentive/ inattention" (N = 58) appear mainly between 1989 and 1992. For example, one narrative reads "preoccupied, driver failed to stop." Another notes, "distraction, driver did not see flashers." The object of inattention, such as the passenger, is not always described.

In an attempt to better understand all the factors pertaining to highway-railway grade crossing accidents, the TSB has added an unsafe conditions/unsafe acts classification section to its reporting after 1999 to allow for the more useful causal categories to be applied. The "why" or probable cause of an accident may be documented in the case file, such as in the unsafe conditions section. Keywords found in the literature were identified, tested against RODS, and a revised list was used for the final searches.

Narratives were extracted from the 7,776 incidents entered into RODS (as of November 7, 2001). A keyword search was performed using the broad categories of distraction, intentionality, visibility/weather, fatal, second train, alcohol-related, and intersection-related. Of the 7,776 crossing accidents in RODS, 6,402 had a narrative. Of the missing 1,374 narratives, 1,307 were missing from the years 1983 to 1989. Only 67 narratives were missing for the years 1990 to 2001. Insufficient details of narratives prior to 1990 overly constrained analysis. As a result, accident narratives (N = 3,990) from 1990 to 2001 were used to perform the qualitative analysis. A number of methods were used to generate the final list of keywords, including test text searches, consultation with related literature, and thesaurus look up. The guiding principle was to use as many viable words, defined as those bringing up cases that meaningfully matched the subcategory, as possible (Landauer, 1991). Many of the returned narratives were incomplete descriptions of the accident events. Frequently, multiple factors were evident in the accident descriptions. The frequency of accidents in any one category is not necessarily representative of the distribution of accidents at highway-railway grade crossings.

7.2 Accidents Related to Intentional Acts

In the context of a highway-railway grade crossing accident when a driver ignores the active and passive signals and signs, often in an attempt to beat the train, the act can be interpreted as an intentional violation (Reason, 1997). Willful violations include driving around the gates, driving around cars stopped at the crossing, and suicide attempts. It is less clear whether driving too fast for the weather and road conditions or not stopping for stop signs or traffic lights at a crossing are always intentional acts (see, e.g., Dennett, 1995; Reason, 1990). Table 7.1 summarizes searches of RODS using intentional acts keywords.

Table 7.1 Intentional acts, number of narratives for each type and a sample narrative. Files searched from 1990 to November 7, 2001 (N=3,990).

Intention Type	**Number of Narratives Found**	**Sample Narrative**[a, b]
Drove Around Gates	35	Train contacted front of a northbound vehicle at a public crossing equipped with flashing light signals, bells and gates. Rail company report indicates vehicle had entered the southbound lane to pass the gates.
Attempted to Beat the Train	16	RCMP reported that the semi-trailer truck driver was following a vehicle that was taking him to the location where he would unload his load of logs… The first vehicle drove over the crossing and stopped while the semi-trailer slowed down then sped up over the crossing in an attempt to beat the train.
Stopped, Then Proceeded	10	Train crew noticed a grain truck stopped at crossing and then at the last moment (it) attempted to pull across the public crossing.
Drove Around Vehicles Already Stopped (or Slowing) at the Crossing	10	Failed to stop. Driver of vehicle travelling southbound passed by on right hand side (wrong side) of three vehicles stopped for train movement. The errant vehicle collided with the right front corner of unit. Driver received minor injuries.
Alcohol	5	Police report that alcohol was involved and that the driver had his licence suspended from a previous driving conviction. The crew had manually protected the crossing, entrained the helper and were almost at the end of the crossing when the vehicle struck the side of the unit.
Drove Around Stopped Vehicles and Gates	4	Rail company reported the vehicle had driven by 2 stopped vehicles, around the crossing gates that were down and was struck by the train.
Slowed, Then Proceeded	3	Failed to stop. Reason unknown. … Driver slowed down then proceeded.
Fatigue	3	The driver had been working late and she was very tired as she approached the crossing and stopped her vehicle. She may have dozed off briefly and awoke abruptly. She did not realize that the train was still on the crossing and that the gates were down when she allowed her vehicle to move forward and drove into the side of the train.

a) Where necessary only the pertinent section of the narrative related to driver behaviour is listed.

b) Other than the omission of identifying details, the narratives have been reproduced as they appear in RODS (spelling errors were corrected).

7.2.1 Drove Around Gates

Driving around a gate or other vehicles to cross a track is obviously intentional. "Drove around gates" is documented throughout RODS and is one of the primary behaviour types identified in narratives from 1983 to 1989. The extent of those narratives, as already noted, is limited. For accidents between 1990 and November 7, 2001, "drove around gates" is part of a larger description of what the driver did at the crossing in 35 cases. Four additional cases describe drivers who drove around cars already stopped at the crossing and then also drove around the gates. These are remarkably bold violations as gates usually indicate the presence of a train. However, in one accident (not included in the 35), a driver went around the gates because they appeared to be malfunctioning. The driver became impatient waiting for them to go up after one train had passed and then decided to go around without noticing that a second train was approaching the crossing. This is a case of mistaken interpretation by the driver as well as a second train situation that is commonly not expected by drivers and pedestrians.

7.2.2. Attempted to Beat Train

The category "attempted to beat train" appears throughout all the time frames of RODS. For the time period 1990-2001, 16 cases of "attempted to beat train" were returned. In a few cases, witnesses noted that a vehicle slowed down, then sped up again in an attempt to cross the tracks before the train reached the crossing. Based on keywords and interpretation of the narratives, there were also 10 cases where drivers "stopped, then proceeded across the tracks" and 3 cases where drivers "slowed, then proceeded across the tracks." For example, a driver who stops then crosses directly in front of the train may be attempting suicide or may have failed to see the train altogether. In some cases in which the narrative cited the driver as attempting to beat the train, it is also noted that the driver slowed at the crossing before speeding up. Observational studies have found that drivers tend to slow down as they approach a railway grade crossing (Moon & Coleman, 1999; Ward & Wilde, 1995b), possibly to scan for approaching trains. Other perceptual factors could affect the driver's ability to see the train, even if the driver slowed to survey the crossing. Differentiation between the categories of "attempted to beat train" and "slowed, then proceeded" require that a further determination be made between an intentional act and "failed to see", respectively. However, given the number of studies that document crossing violations (e.g., Abraham et al., 1998) and question drivers about their intentions at the crossing, it is probably safe to conclude that as least some of these 29 cases involved an intentional violation of the crossing.

7.2.3 Drove Around Vehicles Stopped or Slowing at the Crossing

There were 10 cases where the narratives indicated that a driver drove around stopped or slowing vehicles at crossings without gates. Again, the deliberate nature of these acts allows for relatively simple attribution to wilful violations. As with "drove around gates," drivers who pass vehicles stopped at a railway crossing may cross into the oncoming lane to do so on two-way streets or highways.

7.2.4 Alcohol-Related Incidents

There were only 5 narratives found that mentioned alcohol as a contributing factor from 1990 to November 7, 2001. However, there were 39 cases between 1983 and 1989. The lack of reference to alcohol-related accidents after 1990 might reflect the fact that there is a field in RODS in the unsafe conditions section where an investigator can note whether alcohol was involved or not. There were 16 accidents attributed to alcohol between 1998 and 2001 in the unsafe conditions section. A limited number of alcohol/drug incidents are listed in the FRA tabulations (2001). Alcohol-related accidents peak at night (Moskowitz, 2002). Highway-railway accidents peak during the day. However, given the prevalence of alcohol in approximately 40% of fatal traffic accidents (Evans, 1991), the frequency of narrative descriptions was expected to be greater.

7.2.5 Fatigue

The keyword search found only 3 cases related to fatigue from 1990 to 2001. In 2 narratives, the vehicles were stopped on the crossings and the drivers were presumed to be asleep. Fatigue is thought to be a major contributor to vehicle accidents (Brown, 1994). However, identifying its presence when an accident occurs is problematic (Brown, 1995; Smiley, 2002). The placement of fatigue in the intentional acts section is relevant because many drivers are often aware of their fatigued state but continue to drive anyway. Therefore, although they may not deliberately set out to violate a crossing, missing signals or failing to detect a train because of fatigue implies a level of intention. The narrative that best defines fatigue in the context of a railway crossing accident is the one in which a woman had just come off the night shift. She stopped her car at the crossing, then dozed off briefly at the wheel. When she awoke, she failed to realize that the gates were still down and the train was still on the crossing and drove into the side of the train. Presumably, she was disoriented upon awakening.

7.3 Distraction-Related Accidents

With the prevalence of cellular telephone use while driving, driver distraction and its relationship to accidents has been the focus of numerous media reports and the cause of a number of tragic accidents. Similarly, distraction is frequently cited as a contributor to a certain percentage of railway crossing accidents. In a recent case study, driver distraction was cited as a probable cause in 12 of the 60 cases (20%) reviewed (NTSB, 1998a). Using the keyword search, 39 cases were attributable to distraction. Variants of distraction were also searched for. The terms "preoccupied", "distracted", and "inattentive" appeared frequently in 1989 to 1992. However, what distracted the driver is not always included in the narrative. Narratives that included the terms "preoccupied", "distracted", or "inattentive" but did not include a cause of distraction were excluded from this section. The narratives reviewed here are from 1990 onward. Narratives that exemplify each category and frequencies for 1990 to 2001 are found in Table 6.3. An inherent limitation of putting items into a single category is overcome by the use of narrative searches. Assignment of accidents to a single category makes little sense if accidents are multiply determined. Multiple determinants are frequently described in the narratives.

Table 7.2 Types of distraction, number of narratives for each type and a sample narrative. Files searched from 1990 to November 7, 2001 (N = 3,990).

Distraction Type	Number of Narratives Found	Sample Narrative[a, b]
Did Not See Signals and/or Train at All (no explanation for failure to observe train or signals)	12	Train proceeding westward struck a vehicle on a public crossing equipped with flashing light signals and bell. ... The driver stated to RCMP that he did not see the crossing protection and had made no attempt to stop.
Saw Train Too Late to Stop (late detection)	9	Train crew reported a vehicle struck the side of locomotive at a public crossing equipped with standard reflectorized crossing signs. ... Police report that vehicle driver did not see the train until the last minute and attempted to stop, slid 12 feet before striking the locomotive.
Talking on Cellular Phone	7	While proceeding eastward, train XX-XXX was struck by a southbound tractor-trailer truck at a crossing equipped with standard reflectorized crossing signs. The driver was fatally injured. No dangerous goods involved. No derailment. Damage reported to 2 locomotives. The tractor struck the left front side of the lead locomotive. There was a small explosion and the cab of the tractor was engulfed in fire. There were no skid marks. The driver was using his cell phone to get directions from a proceeding driver as to how to drive where he was to pick up a load of peas in the semi trailer and pup.
Internal Distraction (cognitive processes; e.g., worrying, preoccupied)	4	The vehicle was travelling eastbound on the south side road parallel to the track. The driver did not stop at the intersection as required by the stop sign, but turned north onto the crossing and was struck on the driver's door by the train. A witness heard the train whistle and she saw the driver look up the hill to the north and then look to the south before she turned north onto the track. They were late for a parade. The driver lived within 2 blocks of the crossing.
Talking with Passengers	3	Talking to passenger and children making a lot of noise in the backseat.
External Distraction (events/objects outside the vehicle)	3	Lack of attentiveness – Engineer observed a bailer farm machine eastbound on highway stopped in the media strip waiting for west traffic to clear. When it was clear the driver proceeded and ran into south side of unit. Driver sustained serious inj.
Radio/Tape	1	The vehicle was travelling northward and made no attempt to stop as he did not notice the automatic protection operating due to the sun shining on the lens of the lights. He had his radio on and windows closed. He was attempting to change his radio from tape to radio to listen to a talk show.

a) Where necessary only the pertinent section of the narrative related to driver behaviour is listed.

b) Other than the omission of identifying details, the narratives have been reproduced as they appear in RODS (spelling errors were corrected).

7.3.1 Did Not See Train/Signals

Ten narratives show that the driver failed to see the train at all before colliding with it. These cases were classified based on the "did not see train or signals at all" description, despite a few of them including the terms "preoccupied" or "distracted". The reason for putting them in this category rather than omitting them or placing them in a general distraction (e.g., preoccupied) category is that these narratives do not include a reason for why the drivers were "preoccupied". As in the late detection category, eight of the ten accidents occurred at passive crossings. The other two occurred at crossings with flashing light signals and bells, but no gates.

There are several physical and perceptual characteristics that prevent drivers from detecting trains at passive crossings. These include such things as sight distance down the track from the road, the angle of the intersection, and the roadway or track curvature (NTSB, 1998a). Furthermore, objects in the driving scene, such as other vehicles, signs other than the crossing signs, vegetation, or buildings, may obscure or distract a driver's visual attention away from the crossing, the rail warning signs, or a train (Lerner et al., 1990).

7.3.2 Late Train Detection

In the nine "late detection of train" narratives, drivers stated that they did not see the train in time to stop. Insight into why the drivers did not see the train before it was too late, like other incidents, requires tenuous inference. Eight of the nine collisions in which the driver "did not see the train until too late" occurred at passive crossings. Whether the advance crossing signs were noticed is not known.

7.3.3 Cellular Telephones

Seven cases of cellular telephone involvement were found. Of these, only one narrative indicates the conversation content was a possible contributor. The full narrative is found in Table 7.2. Apparently, the truck driver was obtaining directions from another driver while driving in an unfamiliar area. Absorption in obtaining directions may have limited the driver's capacity to attend to an approaching train or the reflectorized AWS. The lack of skid marks suggests that he might not have seen the train at all and made no attempt to stop. One incident involved a C.B. radio, which is somewhat analogous to the distraction of a cellular telephone, but from another technological era.

7.3.4 Internal Distraction

Internal distraction is defined as being distracted by internal cognitive processes, such as daydreaming, worrying, or being excited about an event in one's life (Wigglesworth, 1979). The narrative search revealed four different examples of internal distraction. In the first case, while a driver was stopped at the crossing, she did not notice she had released the brake and the car rolled into the side of the train. The second case, which is quite similar to one cited by Wigglesworth (1979), describes a mother who was taking her sick child to the hospital when the accident occurred. Wigglesworth's example is that of a mother who was returning home to take care of her other children after having spent the whole day at the hospital with her injured daughter. In the third case, a man drove in front of a train after having just left a store where he had an altercation with the clerk. Apparently, the driver drove around the activated crossing gates while one train was stopped on the near track. The gates were not activated for the train on the near track, but for a train approaching on another track from behind the stopped train. This other train struck and fatally injured the driver. Whether the man's mental state contributed to him driving around the gates must be interpreted cautiously as the driver was killed in the incident. Witnesses, who did not necessarily know the intent of the driver, provided the account of the accident. In the last case, a vehicle with four people (two adults, two children) inside drove through a stop sign prior to the highway-train crossing and made a right turn in front of a train. The driver lived just two blocks from the crossing, but the group was late for a parade in town.

This particular accident also illustrates a number of common contributors to railway crossing accidents. First, the driver could have been distracted by the interactions between the three passengers. Second, the driver may have been preoccupied by a desire to reach the parade on time. Third, being familiar with a crossing does not necessarily reduce one's risk of having an accident, especially if trains are infrequent on the crossing (Wigglesworth, 1979; NTSB, 1998a).

Finally, the driver was required to stop at a stop sign before he turned across the tracks. The driver may have been looking for traffic to his left instead of down the tracks for a train. The driver did not stop at the stop sign, however. Violating the stop sign may also have required his attention to the potential of crossing vehicles and the train crossing was forgotten. Violations compounded by additional driver errors are a recipe for disaster (Reason, 1997). Overall, the relative importance of any one of these four factors in isolation or together is difficult to determine because the driver was killed.

7.3.5 Conversation with Passengers

The search identified three narratives that suggest talking with passengers is also a distraction. In two narratives, multiple factors are cited as possible contributors. The outcome of one accident, which included passenger conversations and listening to the radio, was that the driver drove through a stop sign. In the other multiple distraction case, the driver was conversing with the passenger and their children were in the back seat making a lot of noise.

7.3.6 External Distraction

External distraction occurs when objects or events outside of the vehicle distract a driver (Treat et al., 1979). Three narratives were found for this category. First, a driver was distracted while watching another vehicle. Second, a driver was waiting on the median of a highway for traffic to clear. When it did, he drove across the road and into the side of the train. Third, a driver was watching oncoming traffic when the train hit his vehicle. Overall, it is not entirely clear exactly what manoeuvres (e.g., a turn) drivers were attempting to make when they entered the crossing.

7.3.7 In-vehicle Device

There was only narrative where the use of an in-vehicle device (other than a cellular telephone) was cited a possible cause of the accident. The case involved a driver who was attempting to switch his radio from tape to radio to listen to a talk show. In addition to manipulating the radio, he was driving into the sun, which hindered his ability to see the flashing light signals.

Furthermore, the windows were closed, which may have prevented him from hearing the train whistle. Multiple accident causes are a recurrent theme.

7.4 Visibility Problems

Although visibility issues may not seem to be directly related to driver behaviour at railway crossings, some inferences about accident causes may be derived from understanding how the visibility of the tracks from the roadway affect a driver's ability to detect the presence of a train. Weather-related problems such as fog, sun glare, and blowing snow may obscure a train or reduce the distance at which the train can be viewed in time to stop. In some cases, it may be appropriate to ask the question of whether the driver was travelling too fast for the conditions.

7.4.1 Fog

Twenty-five narratives between 1990 and 2001 cited fog as a probable cause for why an accident occurred. None of these narratives provided information about whether drivers might have been going too fast for the conditions. Of the 25, 17 incidents involved the vehicle striking the side of the train and only three involved the train striking the vehicle. In five, it was unknown whether the train hit the vehicle first or vice versa. Seventeen of the accidents occurred while it was dark. Darkness and fog in combination most likely obscured the visibility of the train, but the extent of the conditions is relative. For example, one investigator may cite "heavy fog" while another simply states "foggy conditions". The presence of "heavy" in the first case does not adequately differentiate from the "foggy conditions" in the second case. For some, the language of "fog", like the language of "snow", can be finely discriminated. These adjectives do not seem to have made it into the narratives, and if they had, how many subtle degrees of "could not see the train" are needed to adequately describe an accident?

In a more extensive investigation by the TSB, a collision between a gravel dump truck and a train with dangerous goods in Alberta occurred in thick fog (TSB, 1995, December). Thirty-four cars derailed and three tank cars were punctured, spilling approximately 30,000 gallons of diesel fuel. Another gravel truck from the same company struck the 48th car of the train and derailed it about

10 minutes after the first collision. An empty school bus drove into the ditch to avoid hitting the second dump truck. The crossing signals were destroyed by the first gravel truck. Minor injuries were sustained by both truck drivers and six houses nearby were evacuated. The fog had reduced visibility to about 10 m (33 ft.) and created icy road conditions. Neither driver saw the AWS in the heavy fog, and the first driver did not see the flashing lights at the crossing until he was very close.

A similar accident had been investigated by the TSB previously in Highgate, Saskatchewan (TSB, 1994, March). In thick morning fog, a truck towing a cattle trailer struck a train and derailed it. The stopped train was struck again by a semi-trailer, derailing another car. Two occupants died and four required medical treatment. Fog was frequent in the area. The crossing had flashing lights and a bell on a pole hung over the roadway as well as AWS's. The road authority and railway installed active advance warning lights with 12-in. lenses (8-in. lenses are standard).

7.4.2 Sun

Sun glare poses a problem for drivers at railway crossings. From 1990 to 2001, there were 21 narratives where sun glare was considered a contributor to the incident. In three of these incidents the sun was setting and in three it was rising. In 15, the glare was due to another factor (e.g., glare off the pavement) or simply described as the sun in the driver's eyes. Sun glare may hinder the detection of crossbucks and flashing light signals at crossings (Mortimer, 1988).

7.4.3 Sight lines

The view of an approaching train may be obscured from the driver's view for a variety of reasons. Sight-line problems include such things as sight distance down the track from the road, the angle of the intersection between the track, and the roadway or track curvature (NTSB, 1986; 1998a). Furthermore, objects in the driving scene, such as other vehicles, signs other than the crossing signs, vegetation, or buildings may obscure or distract a driver's visual attention away from a train approaching the crossing (Lerner et al., 1990; NTSB, 1998a).

Within RODS, information about the visibility of the track from the roadway resides in several locations. First, the sight lines are classified as "poor", "fair", and "good". Second, the crossing angle is recorded in another field and is often the smallest crossing angle, not the accident angle. Third, types of structures that were considered to obscure vision (e.g., houses, vegetation) are located in another field. Narrative searches based on sight-line problems might reveal more about the nature of sight-line issues, as the quantitative data are limited to the subjective ratings of "poor", "fair", "good", and estimated intersection angles.

The search from 1990 to 2001 revealed little additional information about sight-line issues. Only 10 cases were returned that were related to sight-line problems. For example, one mentions "extremely poor sight lines", while another states "sight obstructed severely from south." These are earlier accidents that do not include any extra information in the other available fields. A 1997 narrative reads "… due to the angle of the crossing the occupants did not see or hear the train." This narrative is accompanied by an estimated angle in the database of 30°, which indicates the driver may have had to look over his or her shoulder to locate the approaching train. Two narratives indicated the angle of the crossing: one was 4° and one was 45°. Finally, three narratives indicated that snow banks piled on the side of the road obscured the train's visibility.

A number of TSB railway accident reports discuss crossings that had varying restricted sight lines and drivers who failed to see approaching trains (e.g., see TSB, 1991a, January; TSB, 1991b, January; TSB, 1993, September). However, one driver did not appear to even notice the AWS's, including advisories to reduce speed to 20 km/h (TSB, 1991a, January). The crossing lights and bells were activated and visible. The train whistle was sounded and the forward light was shining. According to the engineers, the driver never engaged in action to slow or stop and was struck and killed. There does not appear to be any reason for failing to stop for the train. In one case, a pile of laundry in the passenger seat obstructed the driver's view of the approaching train (TSB, 1991b, January). The driver did not react to the AWS's, the lights at the crossing, or the approaching train, and was struck and killed. In another case, six occupants of a vehicle were struck and fatally injured at about 6:01 p.m. on September 4, 1993, in Ontario. The relevant sight line to the train had brush and small trees impeding the visibility of approaching trains. The driver was proceeding into the sun in the west. A stop sign was installed at the crossing but was obscured by telephone poles until 200 m from the crossing. The driver had both alcohol and THC in his blood. The alcohol level was the equivalent of one drink, whereas the THC levels indicated the potential to impair driving performance. The alcohol and THC are cited as contributors to the driver's failure to avoid the train.

7.4.4 Snow

Snow can occur throughout the year in parts of Canada. Snow conditions may prevent a driver's ability to see the approaching train. Eight incident narratives described either blowing snow or snow storms impinging on visibility. Whether the driver was engaged in appropriate behaviours, such as driving slower to accommodate the conditions is not always known. Failure to adequately adjust vehicle speed to snow or fog conditions is a common accident contributor.

7.5 Crossing Accidents that Occur Near a Road-Road Intersection

When a road-road intersection is located near a crossing, a driver may be distracted when navigating the intersection and fail to detect the railway crossing (Bremer & Ward, 1997; Wigglesworth, 1979). A keyword search on the narratives was used to determine whether this accident scenario could be identified. From 1990 to 2001, 31 cases occurred, in part, because of their proximity to another intersection. Perhaps the simplest category to understand are those accidents where drivers find themselves stopped on the tracks because traffic ahead is stopped at an intersection. Vehicles behind the drivers may box them onto the tracks. From the narratives, 14 cases of traffic stopped on the tracks occurred. One easy way for drivers to avoid this particular situation is simply not to enter the crossing unless they are sure there is room to exit the crossing on the other side. Appropriate AWS's to help keep the tracks clear—such as interconnections with warning systems and crossing signals, and "do not stop on tracks" signs—are necessary in this scenario. This is analogous to drivers who enter a road intersection even though there is not enough room to exit the intersection because of traffic stopped ahead.

There were six cases where drivers turned left and 11 cases where drivers turned right from either a stop sign or a traffic light and then proceeded into a crossing without observing the train.

Because higher levels of attention are needed to navigate intersections, drivers' attention may be focused on ensuring it is safe to make the right or left turn and they then fail to assess the crossing appropriately before entering it. In the case of the right turn, drivers may look left, away from the crossing, for traffic and not direct their attention back to the tracks until they have finished making the turn. In the case of a left turn, drivers' attention may be directed at oncoming traffic, whereas the train may be approaching from behind on the track parallel to the roadway.

Two police officers were struck and fatally injured when they did not respond to AWS's and FLBs on October 24, 1993 (TSB, 1993, October). Their route, prior to their collision, was to turn left through an uncontrolled intersection and then proceed through a highway-railway crossing one block later. The flashing lights of the automatic device at the crossing were not focused so that vehicles turning left would receive maximum benefit. A building obscured the sight line to the approaching train. A passenger train travelling at 68 mph (108 km/h) struck the police cruiser that was travelling at 10 to 15 km/h. The sun was just to the left of the direction of travel of the police car. It could not be determined whether the visors of the cruiser were up or down at the time of the collision. If they were down, they would have obscured the flashing lights until just before the cruiser entered the highway-railway grade crossing. The brake lights of the cruiser never came on and the officers were never observed looking in the direction of the train. The officers were not in an emergency response mode. Addition of gates to the crossing was suggested by the TSB.

7.6 Second Train/Multiple Track Accidents

In second train accidents, a train goes by in one direction, and then the driver makes a decision to cross the tracks and is hit by a second train that is either following the first train or is on another track coming from the opposite direction. In the latter case, the first train may obscure the second train. In the former, the driver may not expect the approach of a second train from the same direction on the same track or an adjacent track. The keyword search found 10 narratives from 1990 to 2001 that included a description of a second train being present. In six cases, the vehicle was struck by a train coming in the opposite direction of the train the driver had originally stopped to wait for. In two cases, the vehicle was struck by a train that was following the first train. In the final two cases, it is unclear from the narrative which direction the second train was coming from.

7.7 Qualitative Analysis Summary

The qualitative analysis provided additional descriptions of patterns of accidents associated with intentional acts and distraction-related accidents. The importance of providing elaboration of accidents is to provide convergent evidence to support the quantitative analyses and to provide in-depth descriptions. To our knowledge, the application of this method to highway-railway crossing accidents has not been done previously. For this analysis, 3,990 narratives between January 1, 1990, and November 7, 2001, were subjected to a keyword search.

- Of the 86 narratives where the driver intentionally acted, in 35 cases drivers went around activated gates, and in 4 cases drivers went around both stopped cars and gates. In 10 cases at flashing-light-only crossings, drivers went around stopped or slowing vehicles at the crossing. These types of violations are bold in that they usually require the driver to enter the oncoming traffic lane.

- In 16 cases, drivers were noted to have attempted to beat the train over the crossing. However, cases where a vehicle slows, then proceeds (10 cases) in front of a train may actually reflect the normal behaviour of drivers at crossings. That is, drivers tend to slow down on grade crossing approaches, and drivers assumed to be intentionally attempting to beat the train may have simply failed to see the lights or AWS's on the approach.

- There were only 5 narratives found that mentioned alcohol as a contributing factor. The frequency of narrative descriptions for alcohol-related incidents was expected to be greater. However, alcohol can also be queried as an unsafe condition. Three narratives indicated fatigue as a factor.

- Thirty-nine narratives identified driver distraction as a contributor to a crossing accident, and in 21 cases, drivers saw the train when it was too late to stop in time (9) or failed to detect either the train or signals at all (12).

- In 7 narratives, the use of a cellular telephone was indicated as a contributing factor.

- Four narratives indicated the presence of an internal distraction (e.g., a cognitive process such as worrying) and 3 indicated the presence of an external distraction (e.g., an event or object outside the vehicle that attracts attention). An internal distraction may draw attention away from the driving environment in general, whereas an external distraction may draw attention away from an important part of the driving environment.

- Three narratives indicated the drivers were distracted by a conversation with passengers and one narrative indicated that the driver was distracted while attempting to adjust his radio.

- Sixty-four narratives revealed visibility problems at the time of the accident, such as the presence of fog (25), sun glare (21), sight-line obstruction (10), or snow (8). Overall, in cases where fog or snow was cited, it was unknown whether drivers were driving too fast for the conditions.

- Thirty-one narratives noted that a driver was required to navigate an intersection just before reaching the crossing. Although AWS's in Canada exist to indicate the presence of a crossing near an intersection (see Figure 2.1), whether drivers ignore these signs, do not comprehend them, or simply fail to see them is not known. Accidents like this have been documented in previous studies of grade crossing accidents.

- Ten narratives indicated that a second train was involved in the accident. This type of accident occurs when a driver assumes the tracks to be clear after one train passes and is struck by a second train after entering the crossing.

- The capacity for drivers to see passive AWS's and crossing flashing lights in thick fog is severely restricted. In locations where fog is common, the use of active AWS's with larger lenses should be considered.

8. CONCLUSIONS AND RECOMMENDATIONS

To highlight the contributions of this report and to identify gaps in knowledge, 12 conclusions and recommendations are made. In particular, literature reviews and original data analysis contributions are discussed in terms of contentious issues and future research.

1) The significance of this project was the characterization of Canadian highway-railway grade crossing accidents over time and in-depth from a human factors perspective. The quantitative and qualitative analyses supplemented by the TSB unsafe acts and conditions categorizations provide a thorough and unique description of Canadian highway-railway accidents. Statistical comparisons can now be made based on replications and extensions to the present research.

2) Comparisons between TSB highway-railway grade crossing accidents and FRA incidents for 2000 indicate similar patterns for gender, time of day and month, vehicle type, and warning type. Weather involvements were different, as expected. Unsafe acts and conditions, crossing angle, driver age, and long-term trends could not be compared.

3) Observations of driver behaviour at highway-railway grade crossings provide insight into the effectiveness of a variety of countermeasures. Crossing familiarity and an expectation that a train will not be present have the potential to lull drivers into complacency or poor looking habits. Automatic warnings that prevent train-vehicle interactions altogether have the greatest potential to reduce accidents, injuries and fatalities. Complete closure and median barriers at already gated crossings are attractive for cost and effectiveness reasons.

4) Although stop signs provide consistent information to drivers, FRA statistics of their involvement in accidents and fatalities are a cause of concern. Stop signs at highway-railway grade crossings are frequently disregarded by drivers. The effectiveness of stop signs in reducing accidents over existing accident rates has not been established. If Canada were to consider the NTSB's recommendation for stop sign use, additional research is needed to clearly establish its effectiveness.

5) Supplementary advance warning signs that indicate what drivers should do as they approach a crossing should be developed and evaluated. In some countries (e.g., Australia, Israel, U.K.), supplementary information may include distance to the crossing and information such as "look for trains" and "do not stop on tracks". Because drivers fail to notice AWS, multiple signs should also be evaluated.

6) Countermeasure effectiveness can be established using a number of methods (e.g., see Hauer & Persaud, 1986). However, the net effect of extensive countermeasure deployment on the overall accidents, injuries, and fatalities cannot be established conclusively (e.g., see Evans, 1985; 1991). The integration of countermeasures at problem highway-railway grade crossings will contribute to the historical reductions already realized. The reduction of accidents, injuries and fatalities will occur with uncertain variability that will be difficult to attribute to any specific countermeasure program.

7) At first inspection, highway-railway accidents appear relatively simple with few contributors beyond the accident scene. However, in-depth investigations of highway-railway accidents may yield additional contributors if the question of why is repeatedly asked. Root cause analysis implies a search for the ultimate cause or causes to an accident (e.g., Leveson, 1995; Rasmussen, 1990; Reason, 1990). Root cause analyses are helpful where organizations may contribute to the occurrence of an accident. Organizational contributors may include the lack of coordination between rail companies and road authorities to resolve unsafe conditions at a crossing. A targeted Class IV investigation by the TSB may yield the extent to which these organizational contributors exist. The extent to which they exist is currently unknown.

8) Studies about driver behaviour at crossings, combined with accident analyses provide guidance for future research. In addition to knowing the effectiveness of stop signs and supplementary advance warning signs, the effectiveness of photo-enforcement and LED flashing lights has the potential to reduce violations and missed FLBs. Little is known about private crossing accidents or the most cost-effective means to increase their safety.

9) Based on the present research, a variety of recommendations can be made to improve highway-railway grade crossing safety. First, clear criteria must exist for determining what number of accidents, injuries, or fatalities should trigger an evaluation of the signs, signals, and gates at a crossing. Second, the standards for determining when active elements should be added to problematic passive crossings must be clearly defined. Similarly, the criteria for improving active crossings with gates or median barriers should be determined. Finally, the extent to which communities and local governments, in cooperation with Transport Canada and rail companies can identify problem crossings and fast-track their improvement should be investigated. Furthermore, these criteria should also identify problematic crossings if used by the RCMP or local police.

10) It is fortunate that the data contained within RODS included highway-railway accidents from 1983 to the present. Although the TSB's mandate is to advance transportation safety, it does not explicitly cover highway safety like the NTSB does in the U.S. Because more Canadians die on highways than by any other mode of transportation by a factor of 10, one suggestion might be for the TSB to consider including highway safety in their mandate.

11) The utility of the taxonomy of highway-railway grade crossing accident contributors is the identification of common patterns across the reviewed literature. In addition, it can guide inductive and deductive searches for driver, environment, vehicle, and physical contributors. The primary and secondary categories can be used to generate hypotheses about individual cases and aggregate data.

12) Transport Canada has been instrumental in the development of new grade crossing standards and regulations (see Transport Canada, 2002c). Once the *Road/Railway Grade Crossing Manual* is adopted, the extent to which existing highway-railway grade crossings adhere to the new standards and regulations will need to be determined. Inspection and modification resources will be needed to achieve this important objective.

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APPENDIX A: KEYWORD SEARCH TERMS

Category	**Keywords used to search Rail Occurrence Database System. All instances of keyword roots were searched as indicated by a *.**
Distraction	DISTRACT* ATTEN* CONCENTRAT* STEREO CD CB (CITI BAND) CELL PHONE MOBILE CONVERS* TALK* HEAT* AIR COND* RADIO CHANG* (as in changing) ADJUST* CASSETT* PREOCCUP* NOT LOOKING
Fatal	FATAL KILL* DEAD DIED DEATH DECEASED
Intersection	INTERSECT* TURN TRAFFIC LIGHTS
Sightlines/Visibility/ Weather	SIGHT* VISIB* FOG SNOW GLARE DID NOT SEE SUN*
Intentional	BEAT DROVE AROUND RACED RACING RACE FAILED TO STOP DID NOT STOP GATE* SPEED* STOP*
Alcohol	ALCOHOL IMPAIRED DRUNK

Category	**Keywords used to search Rail Occurrence Database System. All instances of keyword roots were searched as indicated by a *.**
Fatigue	FATIGUE SLEEPY TIRED DROWSY

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